PROJECT DESCRIPTION FOR 205DA

INVASION DYNAMICS OF PERENNIAL PEPPERWEED, *LEPIDIUM LATIFOLIUM*, AND THEIR CONSEQUENCES FOR PROTECTION OF WETLANDS IN THE SAN FRANCISCO ESTUARY

THE PROBLEM

Successful wetlands restoration is one of the core goals of the CALFED program. Although many specific restoration programs have been proposed and funded, the need for scientifically rigorous experiments with repeatable results and adaptive responses built into the restoration program should remain a major concern of the agency. One of the most serious problems affecting restoration success is the distinct possibility that a restored marsh might be dominated by an undesirable invasive species, an outcome that might be hardly better than the degraded marsh it was intended to replace. Some marsh biologists have even expressed the belief that marsh restoration should not proceed without an effective program to prevent invasion by aggressive exotics (D. R. Ayres, *pers. comm.*).

The threat of invasive plants to the tidal marshes of the lower Delta and San Pablo Bay regions of the San Francisco Estuary is particularly clear for two species. One is smooth cordgrass (*Spartina alterniflora*), a serious problem in fully tidal salt marshes of San Francisco Bay. The other species is perennial pepperweed or tall white top, *Lepidium latifolium*, a tall forb which occurs throughout the Estuary, in alkali sinks, in cool deserts and even annual and perennial grasslands, through all of which it spreads with ease (Mark Renz, *pers. comm.*). Perennial pepperweed is also invading tidal marshes in the San Francisco Bay area, the notable exceptions being isolated, coastal pocket marshes that have no sources of *L. latifolium* propagules.

L. latifolium is a native of Central Asia and southeastern Europe (Young *et al.* 1997). Its worldwide distribution and average abundance apparently are both increasing; new or growing populations have been documented in Norway (Halvorsen and Grostad 1998), the United Kingdom (Burton 1997), the Elbe River Valley (Brandes and Sander 1995), Austria (Melzer 1994) and Spain (Romero and Amigo 1992). In the United States perennial pepperweed is well-established along the Atlantic seaboard and throughout the western states, except for Arizona (Miller *et al.* 1986, Young *et al.* 1996). The invasion of California by *Lepidium latifolium* has been traced to shipments of sugar beets in the 1930s (Robbins *et al.* 1951).

L. latifolium is now widely recognized to be a very dangerous invasive species. The California Department of Food and Agriculture lists *Lepidium latifolium* as a class B noxious weed, the rating used when a species has a known economic impact but varies in its severity so that it is a county rather than state priority. The California Exotic Plant Pest Council classifies it as A-1 the rating assigned to the most invasive plants of wildlands.

Lepidium latifolium fits the profile attributed to a prototypic invasive species (Baker 1974, Rejmanek 1996). It is a member of the mustard family (Cruciferae), a family known for having many weedy species. *Lepidium latifolium* is a perennial that grows quickly and establishes rapidly in a variety of environments, reaches large sizes and produces numerous small and easily dispersed seed. *L. latifolium* combines the persistence and competitive ability of perennials, even while retaining the high reproductive effort of annuals. A well-established stand may produce up to 16 billion seeds ha^{-1} yr^{-1} (Palmquist, *pers. comm.*). In addition, the species is known to disperse and establish readily from broken rhizomes (Trumbo 1994). The species is phenologically early to develop and notably plastic in its habitat requirements, but also very competitive. Blank *et al.* (2002) reported that *L. latifolium* can compete with *Bromus tectorum* in phosphorus-rich soils by producing large shoots, even though root density is generally sparse. In more depleted soils, root/shoot partitioning increases as *Lepidium* grows into deeper layers. The authors suggested that *Lepidium latifolium* may be particularly competitive against shallow-rooted species in marsh environments.

While there is some controversy about the mode of reproduction which is more closely associated with its invasive success (see Miller *et al.* 1986), its growth habit, competitiveness, and ability to saturate the local environment with seeds once a few individuals are established leaves little doubt that the species must be kept out of sensitive ecosystems. It remains unclear, however, how this is to be accomplished. Exclusion of *Lepidium latifolium* from tidal wetlands has a particularly high priority because of its potential to dominate the many areas slated for marsh restoration. With *Lepidium latifolium* already present in many marshes, eradication and reduction of propagule sources may have to be emphasized during the transition period from degraded marshlands back to equilibrium tidal marsh vegetation.

The direct consequences of perennial pepperweed for tidal marsh ecosystems are threefold. It can displace native vegetation in the streamside zone (*Scirpus* spp. in particular). In the upper marsh, *Lepidium latifolium* may reduce biodiversity and it threatens several endangered plants that occur in this zone of tidal marshes (*e.g.*, *Cordylanthus mollis*, *Cirsium hydrophilum*). Wherever it occurs, perennial pepperweed likely will degrade habitat for clapper rails and other birds. Although many bird species find stands of perennial pepperweed attractive for nesting, the stems are brittle and breaks easily, and so ultimately may prove to be detrimental to nest survival (Hilde Spautz , *pers. comm.*). Changes in ecological function and energy flow for the marsh vegetation are more speculative but ultimately may prove to be more important. Its aggressive growth, polyhaline tolerance, persistence in face of attempts to eradicate it and its potential for altering the functional role of estuarine vegetation through competitive displacement make it a very serious threat to marsh restoration programs and therefore a very high priority for control.

Present knowledge offers few options for prevention or control. The three most obvious are to do nothing, use herbicides, or a program combining herbicides and vegetation manipulation. Depending on the first option in the hope that *Lepidium latifolium* will decline naturally, appears to be contradicted by the evidence available to date (Young *et al.* 1997, Blank *et al.* 2002). *L. latifolium* seems to be at a breakout threshold, or may be already out of control. A program of aggressive treatment using herbicides has met with limited success to date (see below) but may be most effective when combined with other methods. The third option, based on minimizing the opportunity for invasion, is attractive but requires information about both the invader and the tidal marsh community that is largely unavailable at the present time.

This proposal emphasizes the need for a systematic assessment of the population dynamics of *Lepidium latifolium* with special reference to seed production and dispersal. Developing this information should reveal how much can be expected of the interaction of population biology and herbicide-based suppression. It is clear that a complete answer might not emerge within the three years of this proposal, but we hope that our contribution will advance our understanding of the problem to permit marsh restoration programs to proceed with enhanced prospects for success.

JUSTIFICATION OF THIS PROPOSAL

This proposal has three specific objectives.

* *To determine the properties of tidal marshes, particularly soil saturation and salinity, governing their invasibility by Lepidium latifolium.*

Previous studies have hypothesized that *L. latifolium* can tolerate saturated soil conditions and increasing salinity (May 1995, Young and Turner 1995, Chen *et al.* 2001, Blank *et al.* 2002) but does less well under these conditions. Some useful clues about the factors limiting *L. latifolium* are offered by the known distribution of the species in tidal marshes. *L. latifolium* is not effective in colonizing the middle marsh; its distribution tends to be bimodal, with the largest concentrations found along tidal creeks and in the upper marsh plain. The second pattern to note is that the distribution of perennial pepperweed along tidal creeks contracts toward lower, higher-order streams as one moves downstream in the Estuary.

Foin *et al.* (2000) have developed a conceptual model of marsh dynamics, suggesting that tidal influx combining a regular water supply and routine flushing of salinity plays a major role in the zonation of tidal marsh vegetation. Both the streamside zone and upper marsh plain feature enhanced drainage and periodic flushing of excess salinity; plants that have narrower environmental tolerances but higher growth rates tend to be localized in these areas. Plants of lower productivity and shorter stature, but tolerant of flooding and/or salinity, occur in the mid-marsh, spreading toward both the streamside and upper marsh in fully saline tidal marshes.

The tidal marsh distribution pattern of *L. latifolium* suggests that the same factors are important determinants of its distribution and abundance. We hypothesize *L. latifolium* responds to favorable drainage and salinity dilution along the banks of tidal channels, where it has proven to be an excellent competitor against the native tule vegetation, particularly *Scirpus acutus*. The same conditions exist in the upper marsh, where drainage is good and salinity leaching occurs at least seasonally. Conversely, *L. latifolium* is least competitive where drainage is poor and salinity elevated in the middle marsh zone. Our observations in tidal marshes match well with the known intolerance of *L. latifolium* to soil saturation and rising salinities in desert soils (Blank *et al.* 2002).

* *To determine the combination of reproductive life history strategies and environmental characteristics that are associated with Lepidium latifolium invasibility.*

There is nothing in the literature on pepperweed dispersal at present and no base to build upon, but this area is so important it must be addressed. The stated objective is too comprehensive to be addressed fully within the scope of this research. There are, however, two priority activities which are practical and worthy of our attention at this time. The first is the role of competition in excluding *L. latifolium* at the germination-establishment phase. Although *L. latifolium* is competitive, it is unclear if it requires disturbance to establish, or if seedlings can invade established stands. The second is the dispersal of pepperweed seed from an established stand in particular size or density thresholds where significant seeds are produced. Both of these have applied as well as basic scientific value. The first is relevant to the potential exclusion of *L. latifolium* from well-established stands and the second will establish the dispersal distance and estimate the potential rate of invasion across the marsh landscape.

* *To evaluate the impact of herbicide treatment on the eradication of Lepidium latifolium and on the recovery of the vegetation community.*

L. latifolium poses a considerable threat to restoration sites, and increasingly so to natural sites as well. In many locales, *L. latifolium* is already well established, minimizing the possibilities for low-cost, highly successful control (Smith *et al.* 1999). With limited other options available, land managers have relied on herbicide intervention. Current control and eradication efforts utilize intensive pesticide, tillage, mowing, and fire regimes (Young *et al.* 1998, Renz, pers. comm.), but with limited success (Table 1). Young *et al.* (1998) found that an application of 2,4-D (as a low volatility ester) reduced pepperweed cover by 98% 10 months after treatment, but that the population recovered to 100% cover in 2 years. Chlorsulfuron, the most effective herbicide, reduced pepperweed cover by as much as 90% 3 years after treatment; in combination with two mowings, reduced cover by 99.5% one year after treatment (Renz and DiTomaso 1999). Use restrictions bar use of the more effective herbicides, specifically chlorsulfuron, in marshes. If herbicides are to be part of the management of pepperweed, glyphosate in combination with vegetation management is the only option at present. Renz and DiTomaso (2001a) found that while mowing increased effectiveness of herbicides in dense infestations, it also reduced the abundance of native plants. Renz and DiTomaso (2002) acknowledge that even the most highly effective herbicide use programs limit re-establishment following treatment. Furthermore, even if control is ultimately achieved, it is not clear how to restore areas in order to prevent reinvasion. Ball and colleagues (N. McCarten, *pers. comm.*) are conducting a study examining how control measures, including herbicide treatments, influence native endangered species in vernal pools in northern California. The outcome of both of these projects should provide a much improved understanding of the merits of herbicide use for pepperweed control. The aggressive nature of this particular invader mandates that herbicides remain at least a treatment option, and even as the only feasible option in some cases. The results obtained by Renz and DiTomaso and by Young *et al.* in Table 1 indicate that a single glyphosate treatment is unlikely to control pepperweed growth in freshwater wetlands. It remains to be seen if perennial pepperweed will be easier to control with less damage to the plant community under higher salinity regimes typical of tidal marshes. This aspect of the research will help guide the development of a comprehensive strategy for herbicide use across the range of tidal wetland conditions found around the San Francisco Estuary.

Table 1. Comparison of most successful control methods, with estimated control one year (and 2-3 years, where available) after treatment.

Treatment	Herbicide	Rate (kg/ha)	Effectiveness (1 yr later)	Effectiveness (2 yr later)	Effectiveness (3 yr later)	Source
Herbicide	Glyphosate	0.6	15%	0%	-	Young *et al.* 1998
Herbicide + mowed once	Glyphosate	3.33	88.75%	-	-	Renz and DiTomaso 1999
Herbicide	Chlorsulfuron	0.11	95%	90%	90%	Young *et al.* 1998
Herbicide + mowed twice	Chlorsulfuron	0.052	99.50%	-	-	Renz and DiTomaso 1999
Herbicide	2, 4-D amine	2.2	95%	0%	-	Young *et al.* 1998
Herbicide	2, 4-D low volatile ester	2.2	98%*	0%	-	Young *et al.* 1998
Disking	-	-	short term reduction	0%	-	Young *et al.* 1998

*after 10 months

In summary, we anticipate the outcome of this project to be a much-improved picture of the requirements and responses of *Lepidium latifolium* in marsh environments, and possibly a strategy for minimizing its dispersal. As such, this research will provide the biological foundation upon which a control strategy can be built.

RESEARCH PROTOCOLS

Details of the Proposed Research

Objective 1. *To determine the properties of tidal marshes, particularly soil saturation and salinity, governing their invasibility by Lepidium latifolium.*

In order to elucidate environmental factors contributing to *L. latifolium* invasion, correlation analysis will be used to regress streamside species and sampling units against environmental factors. Data will be collected at multiple sites spanning the salinity gradient, ranging from full strength seawater (South San Francisco Bay, San Pablo Bay) to totally fresh water (Cosumnes River riparian zone). We expect to sample at a minimum of 7 locations. The unit of sampling will be meter-square quadrats. A minimum of 24 samples, stratified into each of the three main zones (streamside, midmarsh, upper margin) will be collected at each site. Sampling will be intensive, conducted over a period of four weeks in May 2003 to minimize seasonal differences. If sampling variance is high, a second round of samples may be taken in the same time period.

At each sample location, species composition, percent cover, and selected environmental variables (channel salinity, soil salinity, flooding regime interpolated from tide tables, pH, soil particle size, and percent organic matter) will be recorded. Environmental measurements will be taken with a YSI multiparameter meter and a separate pH meter. A Garmin Vista GPS unit will be used to record the location of each sample site.

Results will be analyzed by an appropriate method of correlation analysis. One such method, canonical correspondence analysis (CCA), allows the user to compare species and distribution patterns and environmental variables in a single step by combining regression with multivariate analysis. The analysis will be run using pepperweed as an environmental factor in order to examine species correlations, and then with pepperweed grouped with the other species to affirm that salinity is the dominant gradient responsible for segregating species and to suggest other factors that may be significant determinants. This analysis is essential for determining whether *L. latifolium* distribution is more closely related to environmental factors or to species combinations. CCA does not perform well with bimodal distributions, however, so other methods of analysis may be chosen depending on trends in the data.

We expect the results to confirm our hypothesis that increasing salinity, possibly with flooding regime as a significant covariate, is the dominant environmental factor limiting successful pepperweed abundance. This hypothesis was originally developed from a 2001 experiment measuring pepperweed growth with different salinity and flooding conditions under controlled conditions. The field sampling study should allow us to test the fit of the model and its consistency, under field conditions, with the experimental results.

Objective 2. *To determine the combination of reproductive life history strategies and environmental characteristics that are associated with Lepidium latifolium invasibility.*

Previous research has shown that once *L. latifolium* invades an area, it establishes quickly, then uses local stands to provide seed sources, expanding its invasion through the marsh using streams as dispersal pathways. One of the outstanding questions about the dispersal of perennial pepperweed is whether or not it differs qualitatively from the marsh edge to the streamside zone. Two principal means for pepperweed dispersal (root fragmentation and seed dispersal) have been documented. The rapid establishment of *Lepidium* across the western states, and the source of original introduction suggest that seed dispersal in probably the principal means of long distance expansion. *L. latifolium* routinely produces numerous seed, but the role of seed in colonization has not been quantified. Wind and animal dispersal are important mechanisms for pepperweed colonization, particularly so at the marsh plain, but perhaps throughout. On the other hand, erosion and dispersal of rhizome fragments along stream courses may be equally or more important in accounting for colonization of *L. latifolium* in the streamside zone.

The study of dispersal and establishment from rhizome fragments is technically difficult to quantify and will not be attempted in this study. Instead, we will concentrate on the interaction of environmental conditions on seed production and dispersal in the two zones. Specific hypotheses include:

* *L. latifolium* in the streamside zone will grow faster and produce more seed than those in the upper marsh. In tidal marshes, seasonal increase in salinity will limit growth and seed production, especially at the marsh plain.
* Seed dispersal profiles from stands at the streamside will be smaller because of boundary layer restriction of wind in the tule zone.
* Seed dispersal will reach the middle marsh. The decrease of *L. latifolium* in this zone reflects the failure of establishment rather than a limitation of dispersal.

To test these hypotheses requires a demographic profile of individual plants in the two zones, an empirical study of seed dispersal from isolated stands, and an experimental study of establishment.

Demographic comparisons. Demographic profiling will follow the CCA study, which should identify the environmental correlates and differences between marsh zones. We can then follow this up by constructing demographic profiles under different environmental conditions (ranging from high salinity upland to poor drainage inland of the stream bank zone). We will mark small plants and follow their growth and development in the field through the season. Demographic measures include biomass production (through destructive sampling of similar individuals), branch production, leaf area, and seed production.

We expect the measurement of differences along the salinity and drainage gradients to confirm the results from field sampling and CCA analysis. Furthermore, the demographic data should contribute to defining the habitat requirements of pepperweed and improve our understanding of the conditions which promote or inhibit its invasiveness.

Seed dispersal. Seed dispersal is notoriously difficult to quantify. Nevertheless, we will attempt to do so as part of this study. First, we recognize that deliberate introduction of *L. latifolium* into uninvaded marshes is dangerous and unwarranted, despite its attractive scientific advantages. Instead, as part of the demographic comparison study, we will identify new and vigorous stands of *Lepidium latifolium* that are producing seed, but which are isolated enough to substantiate the assumption that a given plant (or discrete stand) is the seed source. Petri dishes coated with Tanglefoot will be set out in various directions and distances from the stand to estimate wind-driven seed dispersal and thereby to provide an initial idea of dispersal distance. This method cannot be used to estimate the impact of animal dispersal or the role of rhizome fragments. At this point of the study, these aspects seem too technically difficult to be feasible.

The dispersal profiles are expected to help define relationships between environment and potential dispersal by wind.

Seed establishment study. This part of the study will consist of an experimental analysis of the role of an established stand on perennial pepperweed invasion. The experiment will be run in an open-air setting designed to provide natural environmental conditions. This experiment separates the physiological response of *L. latifolium* seed to stresses associated with elevated salinities and anoxia in bare plots from competitive effects due to the presence of a stand of vegetation. The design of this experiment has flooding frequency (daily and weekly) and aqueous salinity (0, 10, 20, and 30 ppt) as main effects in a split-plot design, with salinity assigned to the main plots and flooding assigned to the subplots. Within the subplots, *L. latifolium* seeds will either be sown into bare soil, or into a native stand. We have decided that native stands will consist of single species at representative cover and biomass at ground level in the field, rather than stands representing the community. One reason is practicality in the size of the experiment; the second is that scientifically the pure stands permit cleaner inferences to be drawn about competitive responses. Community invasion can be done at a second stage. The identity of the native will be dictated by the salinity treatment so that pairing will be representative of pairs found in nature. Plants will be propagated from root stock. In fresh and low salinity conditions, *Potentilla anserina* would be a likely competitor; followed by *Scirpus acutus* at 10 ppt; *Scirpus americanus* at 20 ppt; and *Salicornia virginica* at 30 ppt. There will be 8 replicates per treatment. *L. latifolium* seeds will be sewn into the appropriate treatment at a constant rate for all experimental units. Appropriate seed rain rate will be estimated from sampling in fresh water and brackish sites the season prior to commencement of this experiment. Seeding density used in the experiment will be based on samples collected from multiple sites.

Multiple parameters of pepperweed growth will be measured. These will include total number of germinated seeds, total number of rosettes, and if bolting occurs, number of stems, height, relative growth rate, and seed set. Experimental results will be analyzed using ANOVA.

We hypothesize that the competitive relationships, in the context of prevailing salinity conditions, will determine the rate of *L. latifolium* growth and its long-term establishment capability.

Objective 3. *To evaluate the impact of herbicide treatment on the eradication of Lepidium latifolium and on the recovery of the vegetation community.*

Herbicide use will undoubtedly play a central role in pepperweed control and eradication efforts. Although herbicides do not offer an ideal solution in eradicating perennial pepperweed, they are one of the only effective options for treating well-established, mature stands. Many studies have examined methods of herbicide application to improve kill rates (Renz and DiTomaso 1999,Young *et al.* 1998), yet none of those studies have provided an in-depth examination of the response by the plant community to herbicide treatment. This is key information for land managers who may be considering herbicide control, especially in tidal marshes where recovery of the vegetation is essential, or else the treatment would simply open the habitat to *Lepidium* seedling establishment.

The experiment will be a randomized complete-block design, blocked among sites and replicated within sites and pairing treated and untreated plots, with each replicate in a concentric design to create a buffer zone around an inner quadrat in the center of the plot. The inner quadrat will be 1 m^2, surrounded by a 3x3 m buffer zone. The treatment would be applied to the entire quadrat, but measurements will be taken only from the inner one. All vegetation in each plot will be hand-clipped and removed at the beginning of the herbicide application to reduce exposure of the native vegetation to the herbicide. In each case the herbicide will be Aquamaster, an approved aquatic formulation of glyphosate, applied when the pepperweed plants have started to regrow and are maximally susceptible to treatment. The remaining elements of the treatments include 1) only the base treatment, for one year only; 2) repeat the base treatment for a second consecutive year; and 3) addition of a neutral mulch, consisting of shredded plastic and organic materials that decompose slowly, to minimize open soil after herbicide treatment. The experiment will be monitored for a period of three years. Species composition will be established by direct counts, as well as by percent cover. There will be at least 8 replicates per treatment and a minimum of six sites, or three pairs, along the estuary s salinity gradient. Results will be analyzed with ANOVA.

The herbicide experiment should permit estimation of recovery by both the native vegetation and *Lepidium latifolium*. It is expected the clipping and removal will minimize exposure of the native vegetation to the herbicide and perhaps accelerate its recovery. The repeated treatments will help deplete the seedbank and eliminate recovering pepperweed individuals, and the mulch may suppress successive cohorts of pepperweed seedlings.

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Lepidium latifolium is increasingly recognized as a major threat to successful tidal marsh restoration throughout the Estuary. The overall goal of this research is to provide additional insight into the environmental responses and competitive relations of *L. latifolium* that can be used to improve control strategies. The various lines of research proposed contribute to the overall goal in the following ways.

Field CCA analysis is expected to provide 1) quantitative confirmation of the bimodal distribution of *L. latifolium* in tidal marshes; 2) insight into the importance of environmental conditions, especially the key factors of soil saturation and salinity, as they vary from marsh to marsh; and 3) initial indications of the importance of particular vegetation types and stands on the distribution and abundance of pepperweed. The competitive experiments will test the predictions generated by CCA and perhaps indicate the importance of mixed stands for pepperweed exclusion/invasion. However, we have deliberately chosen to use single-species stands, at approximate field densities, to better isolate competitive characteristics and improve potential inferences.

The limited research on propagule dispersal emphasizes the measurement of two demographic properties the influence of size and timing of pepperweed plants on seed production and the influence of wind dispersal on the seed rain. We recognize that this is not adequate to assess propagule dispersal, since neither animal dispersal nor rhizome fragmentation have been accounted for. However, in the context of the work plan proposed here, it seems better to concentrate on what we can do well and recognize that further refinements will have to be addressed later.

The herbicide trials are the link between demographic-ecological characterization and management. Although extensive research has been conducted elsewhere and cited earlier, we expect the herbicide experiments to produce results that will be important in themselves, as well as providing useful links to previous work. The herbicide experiments will 1) provide more extensive information on the response of the native community as well as the weed; 2) identify how these responses change along the estuarine gradient; and 3) help identify which (if any) procedures is more likely to provide satisfactory control with less negative impact on the natives.

We suspect that *L. latifolium* distribution responds more directly to physical factors and is less heavily influenced by competition with the native flora. Whether this is the case directly influences the optimal control strategy. Adopting a policy of ecological management, based on increasing knowledge of *L. latifolium* biology, with a policy of herbicide intervention when exclusion fails is probably the only way to control existing pepperweed populations and to maintain pepperweed-free sites.

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Invasion dynamics of perennial pepperweed, Lepidium latifolium, and their consequences for protection of natural and restored wetlands in the San Francisco Estuary

Project Information

1. **Proposal Title:**

   Invasion dynamics of perennial pepperweed, Lepidium latifolium, and their consequences for protection of natural and restored wetlands in the San Francisco Estuary

2. **Proposal applicants:**

   Theodore Foin, University of California, Davis

3. **Corresponding Contact Person:**

   Ahmad Hakim-Elahi
   University of California, Davis
   Director of Sponsored Programs Office of Research, 118 Everson Hall UC Davis 1 Shields Avenue Davis CA 95616-8671
   530 752-6933
   jmorell@ucdavis.edu

4. **Project Keywords:**

   Nonnative Invasive Species
   Wetlands Ecology
   Wetlands, Tidal

5. **Type of project:**

   Research

6. **Does the project involve land acquisition, either in fee or through a conservation easement?**

   No

7. **Topic Area**:

   Non-Native Invasive Species

8. **Type of applicant:**

   University

9. **Location - GIS coordinates:**

Latitude: 38.118

Longitude: 122.174

Datum:

Describe project location using information such as water bodies, river miles, road intersections, landmarks, and size in acres.

Tidal marsh habitat from Petaluma Marsh in western San Pablo Bay area eastward to Decker Island in the lower Sacramento-San Joaquin Delta.

10. **Location - Ecozone:**

    1.4 Central and West Delta, 2.1 Suisun Bay & Marsh, 2.2 Napa River, 2.4 Petaluma River, Code 15: Landscape

11. **Location - County:**

    Napa, Solano, Sonoma

12. **Location - City:**

    Does your project fall within a city jurisdiction?

    No

13. **Location - Tribal Lands:**

    Does your project fall on or adjacent to tribal lands?

    No

14. **Location - Congressional District:**

    7th

15. **Location:**

    California State Senate District Number: 4th

    California Assembly District Number: 8th

16. **How many years of funding are you requesting?**

    3

17. **Requested Funds:**
    a) Are your overhead rates different depending on whether funds are state or federal?

       Yes

If yes, list the different overhead rates and total requested funds:

State Overhead Rate:	10%
Total State Funds:	113793.78
Federal Overhead Rate:	48.5%
Total Federal Funds:	152271.60

b) Do you have cost share partners already identified?

No

c) Do you have potential cost share partners?

No

d) Are you specifically seeking non-federal cost share funds through this solicitation?

No

If the total non-federal cost share funds requested above does not match the total state funds requested in 17a, please explain the difference:

18. **Is this proposal for next-phase funding of an ongoing project funded by CALFED?**

No

Have you previously received funding from CALFED for other projects not listed above?

Yes

If yes, identify project number(s), title(s) and CALFED program.

not assigned **splittail simulation model** **Lead Scientist's Funds**

19. **Is this proposal for next-phase funding of an ongoing project funded by CVPIA?**

No

Have you previously received funding from CVPIA for other projects not listed above?

No

20. **Is this proposal for next-phase funding of an ongoing project funded by an entity other than CALFED or CVPIA?**

Yes

If yes, identify project number(s), title(s) and funding source.

R/CZ-154 Tidal Marsh Ecology California Sea Grant

Please list suggested reviewers for your proposal. (optional)

21. **Comments:**

budget total is based on 100% state funds with 10% overhead

Environmental Compliance Checklist

<u>Invasion dynamics of perennial pepperweed, Lepidium latifolium, and their consequences for protection of natural and restored wetlands in the San Francisco Estuary</u>

1. **CEQA or NEPA Compliance**
   a) Will this project require compliance with CEQA?

      No
   b) Will this project require compliance with NEPA?

      No
   c) If neither CEQA or NEPA compliance is required, please explain why compliance is not required for the actions in this proposal.

      Project is experimental research to be done in a laboratory setting., except for final testing phase, which will be part of other projects under whose clearance we should be included.

2. **If the project will require CEQA and/or NEPA compliance, identify the lead agency(ies).** *If not applicable, put "None".*

   <u>CEQA Lead Agency:</u>
   <u>NEPA Lead Agency (or co-lead:)</u>
   <u>NEPA Co-Lead Agency (if applicable):</u>

3. **Please check which type of CEQA/NEPA documentation is anticipated.**

   CEQA
   -Categorical Exemption
   -Negative Declaration or Mitigated Negative Declaration
   -EIR
   Xnone

   NEPA
   -Categorical Exclusion
   -Environmental Assessment/FONSI
   -EIS
   Xnone

   If you anticipate relying on either the Categorical Exemption or Categorical Exclusion for this project, please specifically identify the exemption and/or exclusion that you believe covers this project.

4. **CEQA/NEPA Process**
   a) Is the CEQA/NEPA process complete?

      Not Applicable

b) If the CEQA/NEPA document has been completed, please list document name(s):

5. **Environmental Permitting and Approvals** (*If a permit is not required, leave both Required? and Obtained? check boxes blank.*)

LOCAL PERMITS AND APPROVALS

Conditional use permit

Variance

Subdivision Map Act

Grading Permit

General Plan Amendment

Specific Plan Approval

Rezone

Williamson Act Contract Cancellation

Other

STATE PERMITS AND APPROVALS

Scientific Collecting Permit Required, Obtained

CESA Compliance: 2081

CESA Compliance: NCCP

1601/03

CWA 401 certification

Coastal Development Permit

Reclamation Board Approval

Notification of DPC or BCDC

Other

FEDERAL PERMITS AND APPROVALS

ESA Compliance Section 7 Consultation

ESA Compliance Section 10 Permit Required

Rivers and Harbors Act

CWA 404

Other

PERMISSION TO ACCESS PROPERTY

Permission to access city, county or other local agency land. Agency Name:	
Permission to access state land. Agency Name: Cal Fish and Game	Required, Obtained
Permission to access federal land. Agency Name:	
Permission to access private land. Landowner Name: Solano Land Trust	Required, Obtained

6. **Comments.**

Land Use Checklist

Invasion dynamics of perennial pepperweed, Lepidium latifolium, and their consequences for protection of natural and restored wetlands in the San Francisco Estuary

1. **Does the project involve land acquisition, either in fee or through a conservation easement?**

   No

2. **Will the applicant require access across public or private property that the applicant does not own to accomplish the activities in the proposal?**

   Yes

3. **Do the actions in the proposal involve physical changes in the land use?**

   No

   If you answered no to #3, explain what type of actions are involved in the proposal (i.e., research only, planning only).

   research only. There is a possibler exception in field verification, if physical grading is required. The lead agency will acquire the necessary permits.

4. **Comments.**

Conflict of Interest Checklist

Invasion dynamics of perennial pepperweed, Lepidium latifolium, and their consequences for protection of natural and restored wetlands in the San Francisco Estuary

Please list below the full names and organizations of all individuals in the following categories:

- Applicants listed in the proposal who wrote the proposal, will be performing the tasks listed in the proposal or who will benefit financially if the proposal is funded.
- Subcontractors listed in the proposal who will perform some tasks listed in the proposal and will benefit financially if the proposal is funded.
- Individuals not listed in the proposal who helped with proposal development, for example by reviewing drafts, or by providing critical suggestions or ideas contained within the proposal.

The information provided on this form will be used to select appropriate and unbiased reviewers for your proposal.

Applicant(s):

Theodore Foin, University of California, Davis

Subcontractor(s):

Are specific subcontractors identified in this proposal? No

Helped with proposal development:

Are there persons who helped with proposal development?

No

Comments:

Budget Summary

Invasion dynamics of perennial pepperweed, Lepidium latifolium, and their consequences for protection of natural and restored wetlands in the San Francisco Estuary

Please provide a detailed budget for each year of requested funds, indicating on the form whether the indirect costs are based on the Federal overhead rate, State overhead rate, or are independent of fund source.

State Funds

Year 1												
Task No.	**Task Description**	**Direct Labor Hours**	**Salary *(per year)***	**Benefits *(per year)***	**Travel**	**Supplies & Expendables**	**Services or Consultants**	**Equipment**	**Other Direct Costs**	**Total Direct Costs**	**Indirect Costs**	**Total Cost**
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2	seed expt		8187.3	245.62		2000				10432.92		10432.92
2	seed expt	80	824							824.0		824.00
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Year 2												
Task No.	**Task Description**	**Direct Labor Hours**	**Salary *(per year)***	**Benefits *(per year)***	**Travel**	**Supplies & Expendables**	**Services or Consultants**	**Equipment**	**Other Direct Costs**	**Total Direct Costs**	**Indirect Costs**	**Total Cost**
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2	growth expt	200	1470	44.1						1514.1		1514.10
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		360	22305.15	617.24	2000.00	1500.00	0.00	0.00	5072.55	31494.94	3149.49	34644.43

Year 3												
Task No.	**Task Description**	**Direct Labor Hours**	**Salary *(per year)***	**Benefits *(per year)***	**Travel**	**Supplies & Expendables**	**Services or Consultants**	**Equipment**	**Other Direct Costs**	**Total Direct Costs**	**Indirect Costs**	**Total Cost**
3	mesocosm exp		20014.5	600.44	2000	1500			5314.1	29429.04	3486.74	32915.78
3	mesocosm exp	200	1540	46.2						1586.2		1586.20
3	mesocosm exp	200	2266							2266.0		2266.00
3	field test	200	1540	46.2						1586.2		1586.20
		600	25360.50	692.84	2000.00	1500.00	0.00	0.00	5314.10	34867.44	3486.74	38354.18

Grand Total=112793.78

Comments.

Budget Justification

Invasion dynamics of perennial pepperweed, Lepidium latifolium, and their consequences for protection of natural and restored wetlands in the San Francisco Estuary

Direct Labor Hours. Provide estimated hours proposed for each individual.

The Research Assistant associated with this proposal has her annual salary (at UC scale) listed without regard to hours, except that tasks 1 and 2 in yr 1 are split. The salary is calculated at 9 months (academic year) @ 50% time and 3 months @ 100% time. Undergraduate assistants have been calculated as two persons. The hours listed can be divided by 2 to get the individual total. Similarly, casual labor is based on two persons and can be divided in the same way.

Salary. Provide estimated rate of compensation proposed for each individual.

Research Assistants are $1213 per month @50% and 2426/month full time. Student Assistants are 7.00 per hr. Casual Labor is $10.30 per hour. 5% COLA has been included for each year.

Benefits. Provide the overall benefit rate applicable to each category of employee proposed in the project.

The benefit rate for students is 3%. Casual labor has no benefits associated with the salary. The Research Assistant is due university fee remission for each quarter enrolled. This is provided for in the other direct cost category.

Travel. Provide purpose and estimate costs for all non-local travel.

Most of the travel is for local travel, either through vehicle reimbursement or rental of a university vehicle. One conference meeting per year is included, assuming out of state locations but not international.

Supplies & Expendables. Indicate separately the amounts proposed for office, laboratory, computing, and field supplies.

All supplies are directly associated with the proect, including equipment in the first year that does not meet the definition of 5K per item. Computing and office supplies are being paid for by faculty funds. These include new balances, pH meter, GPS locator, and an outboard motor and boat trailer.

Services or Consultants. Identify the specific tasks for which these services would be used. Estimate amount of time required and the hourly or daily rate.

not applicable

Equipment. Identify non-expendable personal property having a useful life of more than one (1) year and an acquisition cost of more than $5,000 per unit. If fabrication of equipment is proposed, list parts and materials required for each, and show costs separately from the other items.

not applicable

Project Management. Describe the specific costs associated with insuring accomplishment of a specific project, such as inspection of work in progress, validation of costs, report preparation, giving presentatons, reponse to project specific questions and necessary costs directly associated with specific project oversight.

Publication and conference costs are the only ones included in this budget. All administrative costs are included in overhead.

Other Direct Costs. Provide any other direct costs not already covered.

Each year includes the fee remission with an anticipated 5% inflation factor. The first year includes publication costs (figures and page charges, reprints).

Indirect Costs. Explain what is encompassed in the overhead rate (indirect costs). Overhead should include costs associated with general office requirements such as rent, phones, furniture, general office staff, etc., generally distributed by a predetermined percentage (or surcharge) of specific costs.

Overhead is 10% of total direct costs by negotiation with the State of California and CALFED.

Executive Summary

Invasion dynamics of perennial pepperweed, Lepidium latifolium, and their consequences for protection of natural and restored wetlands in the San Francisco Estuary

The relatively recent introductions of two highly successful exotics, Spartina alterniflora and Lepidium latifolium, threaten the structure and functional integrity of those remaining Bay-Delta wetlands and may have a devastating impact on marsh restoration. While Spartina alterniflora is the subject of continuing research, comparatively little is known about Lepidium latifolium in light of its potential impact on the Bay-Delta system. L. latifolium has been shown to invade riparian corridors, freshwater, brackish, and saline tidal wetlands successfully. The objective of this proposal is to determine the characteristics of Lepidium latifolium that facilitate its colonization and of the tidal marshes it invades. This research is expected to reveal demographic weaknesses, which when translated into restoration policy, would help check the establishment of Lepidium, enhancing the protection of natural wetlands and preventing its invasion into restored wetlands. The proposed research focuses on the determination of life history and population biology; the combination of reproductive life history strategies and environmental characteristics associated with L. latifolium invasibility; and testing the emerging model of L. latifolium - environment interactions on simulated tidal marshes, with field verification in San Francisco Bay and Suisun Bay sites. The proposed research should enhance the development of a control strategy for one of the areas most noxious wetland weeds. Eradication of this species is extremely difficult or impossible once it is well-established; our expected control strategy will focus on prevention of spread, reduction of threat to restored areas, and mitigation of negative impacts. In addition, this research will provide improved mechanistic understanding of how L. latifolium successfully invades tidal marshes, the environmental determinants of its success and most effective control strategies. By so doing, it will address one of the most serious problems identified in the CALFED Ecosystem Restoration Plan. The research protocol could serve as a model for other exotic wetland plant invaders and so its benefits may reach beyond Lepidium itself..

Proposal

University of California, Davis

Invasion dynamics of perennial pepperweed, Lepidium latifolium, and their consequences for protection of natural and restored wetlands in the San Francisco Estuary

Theodore Foin, University of California, Davis

PROPOSAL TITLE: **INVASION DYNAMICS OF PERENNIAL PEPPERWEED, *LEPIDIUM LATIFOLIUM*, AND THEIR CONSEQUENCES FOR PROTECTION OF NATURAL AND RESTORED WETLANDS IN THE SAN FRANCISCO ESTUARY**

Principal Investigator: Theodore C. Foin
University of California, Davis

Proposal Starting Date: 1 January 2002

Period of Support: 3 years

Budget Requested: $113793.78

THE PROBLEM: MINIMIZING INVASIVE SPECIES IN RESTORING TIDAL MARSHES IN THE SAN FRANCISCO ESTUARY

Successful wetlands restoration is one of the core goals of the CALFED program. Although many specific restoration programs have been proposed and funded, the need for scientifically rigorous experiments with repeatable results and adaptive responses built-in remains a major concern of the agency. One of the most serious problems affecting restoration success is the distinct possibility that a restored marsh might be dominated by an undesirable invasive species, an outcome that might be worse than the degraded marsh it was intended to replace. Some marsh biologists have even expressed concern that marsh restoration should not proceed without an effective program to prevent invasion by aggressive exotics (D. R. Ayres, personal communication).

The threat of invasive plants to the tidal marshes of the lower Delta and San Pablo Bay regions of the San Francisco Estuary is most certain for two species. One is smooth cordgrass (*Spartina alterniflora*), a serious problem in fully tidal salt marshes of San Francisco Bay. Don Strong and colleagues are currently working on the former, mostly in San Francisco Bay but also in Washington. The other species is perennial pepperweed, *Lepidium latifolium*, a tall forb which occurs throughout the Estuary, in alkali sinks, in cool deserts and even annual and perennial grasslands, through which it spreads with ease (Mark Renz, unpublished research).

Lepidium latifolium has received much less attention but it may actually be the more dangerous of the two species. It has vital attributes and a life history that are characteristic of prototypic exotics (Rejmanek, 1996). It is a member of the mustard family (Cruciferae), a family known for having many weedy species, numerous small and easily dispersed seed, and ability to reach large sizes. *Lepidium latifolium* shares these family traits; in addition, it is large (reaching 1 m or more in height) and highly fertile (freely produces lateral branches, each with numerous flowers and small, easily dispersed seed). *L. latifolium* grows fast and has a large, aggressive root system, which enables it to compete effectively with other perennials while retaining the reproductive effort of

annuals, It reproduces by both sexual and vegetative means (Trumbo, 1994). Furthermore, *L. latifolium* may compete with other species by pumping salt ions from deep in the soil profile to the surface, making the immediate surroundings less suitable for other species (Blank and Young, 1997).

One known weakness in the biology of *L. latifolium* is that it is not effective in colonizing the upper marsh. It has some ability to tolerate or survive saturated conditions and the elevated soil salinities found there, but is not known to grow well under these conditions (Chen et al, 2001; May, 1995; Young and Turner, 1995). Consequently, *Lepidium latifolium* poses its gravest threat to the streamside zone, which generally has moderated salinity, abundant water, and better drainage. Despite its relatively recent introduction into Pacific tidal marshes, *L. latifolium* has spread quickly along stream courses, and is considered a serious invader of this zone from full salt marshes upriver to muted tidal and freshwater marshes. In our opinion, its aggressive growth, euryhaline tolerance, persistence in face of attempts to eradicate it and its potential for altering the functional role of estuarine vegetation through competitive displacement make it a very serious threat to marsh restoration programs.

PROPOSAL JUSTIFICATION

Although we naturally focus on invasive species with greater economic or ecological impact, there is little conceptual distinction between biological invaders and recolonization by native species. Colonization by any species is the joint product of site invasibility and those vital attributes of the potential colonist that facilitate its dispersal and colonization. This proposal is organized around this basic principle, focusing upon the relative impact of each component of colonist demography and physiological requirements and environmental resistance.

Prior research with *L. latifolium* suggests 1) that seed dispersal is not limiting; 2) that once plants produce large rhizomes, they cannot be easily displaced; and 3) the critical demographic phase is in establishment and maturation in the first year. Maturation is particularly important since these plants subsequently become local seed sources. Since experience shows that adequate control after establishment is at best difficult and environmentally disruptive, colonization of restoration sites by *Lepidium* must be prevented by some combination of increased site resistance and exploitation of demographic bottlenecks. We seek to estimate the risk of *Lepidium* establishment by measuring site invasibility and defining its colonization strategies from its biological and ecological traits. We can then combine both types of information to test the invasion success by *L. latifolium* in simulated marsh stands and environmental conditions. The goal of this research is to minimize the spread of pepperweed by elucidating the conditions under which it is favored and by potentially providing the opportunity to exploit weaknesses in the life history and population biology of *L. latifolium* to control its spread throughout Estuary marshes.

Adaptive management is expected to be of less concern with this proposal than with restoration programs. Because the research is with a dangerous exotic, most of it will be in the laboratory under controlled conditions. Experiments that do not turn out as

expected are a problem of ordinary science; the adjustments are technically part of adaptive management, but the potential negative consequences are much smaller. The final field tests can fail, and lead to growth and establishment of *Lepidium* despite the design and expectations. The appropriate response under these conditions will be to destroy the *Lepidium* at the end of the first year.

OBJECTIVES OF THIS PROPOSAL

This proposal has three specific objectives.

1. To determine the properties of tidal marshes governing their invasibility by exotic species, with special regard to different positions in the wetland landscape.

2. To determine the combination of reproductive life history strategies and environmental characteristics that are associated with *Lepidium latifolium* invasibility.

3. To test the emerging model of ecological influences on colonization by *Lepidium latifolium* on simulated tidal marshes.

The outcome of this project should be a much-improved picture of the requirements and responses of *Lepidium latifolium* in marsh environments, and possibly a strategy for minimizing its dispersal. As such, this research will provide the biological foundation upon which a control strategy can be built.

PROPOSED APPROACH

Objective 1. To determine the properties of tidal marshes governing their invasibility by exotic species, particularly Lepidium latifolium.

It is important to discover which attributes of tidal marshes in the San Francisco Estuary are key determinants of successful pepperweed colonization. Our previous research has shown that *L. latifolium* is largely restricted to the streamside zone in tidal marshes; often the smaller channels in the marsh are delineated by a mixture of *fringing Scirpus* spp. and *Lepidium*. Our mathematical model (developed from the conceptual model in Foin *et al.* 2000) suggests that a combination of more abundant water supply and regular flushing of salinity acts to open these sites to *Lepidium* colonization. Conversely, the upper marsh may have persistent high water levels with too highly elevated soil salinity to support *Lepidium* invasion. Thus, the principal focus of this phase of the research will be the streamside zone.

In order to elucidate environmental factors contributing to *Lepidium latifolium* invasion, canonical correspondence analysis (hereafter abbreviated to CCA) will be used to regress streamside species and sampling units against environmental factors. CCA

allows the user to compare species and distribution patterns and environmental variables in a single step by combining regression with multivariate analysis. The sampling units will consist of 1 m^2 units. The analysis will be run using *Lepidium* as an environmental factor in order to examine species correlations, and then with pepperweed grouped with the other species to affirm that salinity is the dominant gradient responsible for segregating species and to suggest other factors which may be significant determinants. Data will be collected at multiple sites along a salinity gradient ranging from full strength seawater (western San Pablo Bay sites) to fresh water (Suisun Marsh). The exact sites to be sampled will include Rush Ranch and Petaluma Marsh, plus a series of younger marshes to be chosen from sites along San Pablo Bay and others in the Suisun Marsh in Solano County. A minimum of 20-1 m^2 samples will be collected from each site. Species composition, percent cover, and several environmental variables (channel salinity, soil salinity, flooding regime interpolated from tide tables, pH, soil particle size, and percent organic matter) will be recorded for each sample. Sampling will be conducted in one short time period at each site, but can be repeated in subsequent years if the analysis requires it.

The results will be analyzed using PC-Ord (McCune, 1999) for CCA. We expect the results to confirm the hypothesis that increasing salinity is the dominant environmental factor limiting successful pepperweed invasion. This hypothesis was developed from a 2001 experiment measuring growth under different salinity and flooding conditions under controlled conditions. We next need to confirm these results in the field, with natural conditions of tidal input and soil. It will be particularly important to examine the influence of these covariates as clues to the mechanisms limiting *Lepidium*.

Objective 2. To determine the combination of reproductive life history strategies and environmental characteristics that are associated with Lepidium latifolium invasibility.

Two principal means for pepperweed dispersal (rhizome fragmentation and seed dispersal) have been documented. Field observations have shown that broken rhizomes are an important source of propagules for dispersing pepperweed (M. Renz, pers. comm.). This is a difficult mechanism to study, given the erratic dispersal of broken rhizomes and the numerous conditions that can influence their growth. The difficulty in making satisfactory experimental measurements of rhizome establishment rates is a daunting problem. We concede that rhizomes are probably important propagules, especially after a reproducing population has established either locally or at some location upstream of the site. Our best evidence of significant colonization by rhizomes may be indirect, resulting from seeing successful establishment in the field that cannot be accounted for by seedling germination and growth.

The rapid establishment of *Lepidium* across the western states suggests that seed dispersal is probably the principal means of expansion. *L. latifolium* routinely produces numerous seed, but to date the role of seed in colonization has not been quantified. The copious seed suggests that wind and animal dispersal are important mechanisms for

pepperweed colonization, at least in streamside habitats, and perhaps the most important one.

Seed dispersal and early growth. Because seed are both numerous and readily dispersed, it seems safe to assume that dispersal is not a major limiting factor on *Lepidium* invasibility, and instead concentrate upon establishment.

Experimental seeding in the field has obvious flaws and dangers, so laboratory experiments will be the principal means for assessing the reproductive strategies of *Lepidium latifolium*. This research will examine the success of reproduction from seed in relation to the nature of the stand. We propose to seed pepperweed into stands of native streamside dominants of varying densities, from bare ground to normal densities under different salinities (0, 15, 35 ppt - the range of salinities found in the streamside zone in the Estuary) in the laboratory for better control over site conditions. *L. latifolium* will be seeded into stands of native dominants (*S. acutus, S. americanus. S. maritimus*) to determine the importance of seedling survivorship to *L. latifolium* expansion. This will be a randomized complete block design with salinity assigned to the main plots and *Scirpus* cover randomly assigned within blocks. The number (estimated by weight of seed sown) of *L. latifolium* seeds will be constant across treatments. The response variable will be the estimated number of germinated seeds and number surviving to seedlings and adulthood, broken down into size groups (height <5cm, 5-30 cm, 30-60 cm, and >60 cm). There will be 8 replicates per treatment. Results will be analyzed with ANOVA and quantified by regression equations. We hypothesize that these competitive relationships, in the context of prevailing salinity conditions, will determine the rate of *Lepidium* growth and its long-term establishment.

Post-colonization growth and establishment. *Lepidium latifolium* can be expected to compete against the tules (*Scirpus* spp.) normally found in the streamside zone. The previous experiment should tell us how much tule stands can be expected to resist *Lepidium* invasion. The effect of *Lepidium* on *Scirpus* spp. is the subject of the next experiment. To assess the potential for competitive displacement of tules in tidal marshes, growth responses of *Lepidium latifolium* will be compared to three native wetland streamside dominants (the same three *Scirpus* as in the seeding experiment)across a range of salinity treatments. The experiment monitors the growth of each of the three species in growth boxes under three salinity treatments (0, 15, 35 ppt) and two flooding regimes (daily, every 4th day). The experimental design is a split plot design with salinity as the main plot, flooding regime the subplot, and species identity randomly assigned to the subplots. Plants will be propagated from root stock. There will be four replicates per treatment, and four subsamples in each sampling unit to reduce variability of root stock. The number of replicates is constrained by the number of treatments and plumbing constraints. Preliminary results from a pilot experiment done this year indicate that this is an adequate number of replicates for the variance expected. Above- and below-ground biomass will be collected at the end of the growing season. Growth response will also be monitored throughout the growing season by repeatedly measuring the growth of randomly selected stems in each experimental unit Results will be analyzed with repeated measures ANOVA.

Objective 3. To test the emerging model of ecological influences on colonization by Lepidium latifolium on simulated tidal marshes.

The results from earlier experiments will allow us to identify those species and environmental variables having the greatest effect on *Lepidium* invasion success. These results will permit us to establish stand conditions that should vary with respect to suitability for *Lepidium* seedlings. Such stands will be planted as a validation experiment, set up in mesocosms that will have simulated tidal and salinity conditions to match the combinations having the greatest effect on invasibility. The design will be a randomized complete block design with five replicates. The treatments will be selected from the series of conditions elucidated above that are most applicable to pepperweed invasion. Satisfactory rank order in invasion success will serve to test our understanding.

Successful validation will open the possibility for field tests of planting strategies that can be tested in sites being restored in the field. Although this aspect remains too preliminary to promise as a finite objective, such field experiments will be discussed in our interactions with the Simenstad-Reed-Phil Williams team and the DWR marsh restoration program, both of which will be conducting restoration programs and who have indicated their willingness to collaborate with us. Since we will not deliberately introduce *Lepidium* seed into the field, we will require sites at which pepperweed is already present in the general area. Field validation is one way to address any lingering concerns about our ability to produce satisfactory mescosms (see Callaway *et al.*1997). Whether or not field validation can be performed, we expect this proposal to identify species, planting schemes and environmental conditions which have the greatest exclusionary impact on pepperweed.

FEASIBILITY

This proposal is based on methods that have been well tested in ecology, marsh biology and the field in previous research leading up to this one. The laboratory-based and field survey elements of this proposal are demonstrably feasible and no insurmountable problems are expected to arise therein.

The final field-based tests of *Lepidium* exclusion will require permits. We hope to be included in existing or forthcoming permits at Simenstad-Reed Williams and/or DWR sites. The exact design elements cannot be specified until the laboratory results are in and analyzed, but hopefully will result in feasible restoration schemes (planting densities, species type, and predominant hydrologic-geomorphic conditions).

PERFORMANCE MEASURES

The only aspect of this proposal subject to specification of a successful performance evaluation will be the field experiment. Once the treatments are in place, the experiment will have to be routinely monitored for *Lepidium* colonization, most likely over a two-year period to allow for two germination and growth cycles. *Lepidium*

seedlings appearing in the site are not sufficient to judge the experiment a failure; *Lepidium* must grow and produce seed to meet this condition. If *Lepidium* seed are locally available but there is no successful colonization within the two years, the experiment will be deemed successful.

DATA HANDLING AND STORAGE

All data will be stored in a data vault system maintained and backed up in the Computing Facility of the Department of Agronomy and Range Science, University of California, Davis. Results will be posted to our website at agronomy.ucdavis.edu.

OUTCOMES AND EXPECTED BENEFITS OF THIS RESEARCH

If the research progresses as outlined, we think a testable *Lepidium* prevention strategy will emerge before the end of the project term. By elucidating the conditions under which pepperweed is favored and by potentially providing the opportunity to exploit vulnerabilities in its life history and population biology to control its spread, we should be able to develop an improved picture of the requirements and responses of *Lepidium latifolium* in marsh environments, and possibly a strategy for minimizing its dispersal. This can be further tested in the field or implemented without increasing the risk of *Lepidium* invasion.

We shall participate in future CALFED science conferences, publish in regular journals, and perhaps produce a manual on planting and environmental management that minimizes the risk of *Lepidium* invasion.

WORK SCHEDULE

Objective	Task	Timeframe
1	field survey using CCA	June-September 2002
2	experimental seeding into *Scirpus* spp.	May-October 2002
2	growth in competition with *Scirpus* spp.	May-October 2003
3	mesocosm tests in simulated streamside stands	February-September 2004
3	field verification	February 2005-October 2006

The off-season (November-February) is reserved for data analysis. Above-ground material will be collected from Rush Ranch to support a regression of plant height against biomass for each species. In the fall of 2001, native streamside dominants will be placed into growth chambers to grow them out for the stands of the seeding

experiment beginning in the spring, 2002. We will collect data on species and environmental factors for the CCA in the summer of 2002. In the spring of 2004, the mesocosm experiments will begin and will continue through the fall. Technically, field verification proceeds beyond the term of this proposal, although planting of experimental stands will likely be completed in 2004. Details of monitoring will continue, but exact arrangements will have to be made later.

Applicability to ERP Goals

The four ERP goals applicable to this proposal are:

Goal 1: *protection and restoration of native biotic communities*
Goal 2: *Rehabilitate natural aquatic and adjacent plant communities to support native members of those areas*
Goal 4: *Protect and/or restore functional habitat types in the Bay-Delta estuary and its watershed for ecological and public values such as supporting species and biotic communities, ecological processes, recreation, scientific research, and aesthetics, including restoration of tidal marsh, sloughs, seasonal and riparian wetlands and protecting tracts of existing high quality wetland*
Goal 5: *Prevent establishment of additional non-native invasive species and reduce the negative ecological and economic impacts of established non-natives in the Bay-Delta estuary and its watershed, including where possible limiting spread or eradication of non-natives*

The proposed research will directly address each of these four goals. *Lepidium latifolium* is specifically identified as a major problem in the Bay-Delta estuary and its watershed. This species poses a grave threat to remaining wetlands in the Bay-Delta system and to proposed restoration projects because it is highly successful across a wide spectrum of wetland habitats. This research seeks to provide a mechanistic understanding of the way in which *L. latifolium* is able to invade a wetland site with respect to the invader and the environmental characteristics of the site. Development of a successful control protocol would help protect remaining intact systems; provide a means for reducing its spread; and prevent the invasion of *Lepidium latifolium* into restoring sites.

PREVIOUS CALFED SUPPORT

I have support from the Science Advisors funds (30K) to support mathematical modeling population dynamics of splittail. *Pogonicthys macrolepidopterus*. This work is completely separate from this proposal.

SYSTEM-WIDE ECOSYSTEM BENEFITS

This proposal seeks to develop and test the adequacy of a protocol to address the invasibility of tidal marshes, and secondarily to find management schemes which

maximize exclusion of pepperweed. To the extent to which this proposal is productive, we can expect to improve restoration by excluding *Lepidium*, and perhaps develop a protocol that can be used for a larger number of invasive plant species.

QUALIFICATIONS

ABBREVIATED CURRICULUM VITAE
THEODORE C. FOIN
Updated 9 October 2000

EDUCATIONAL SUMMARY

A.B., Biological Sciences, Stanford University, 1962
Ph.D., Zoology (Ecology), University of North Carolina, Chapel Hill, 1967

CURRENT ACADEMIC POSITION

Professor
Department of Agronomy and Range Science
University of California, Davis 95616
1998-Present

ROUTINE TEACHING RESPONSIBILITIES

ASE 121. Systems Analysis in Agriculture and Resource Management
Ecology 200B. Principles and Application of Ecological Theory.
Ecology 201. Modeling Ecosystems and Landscapes

GRADUATE EDUCATION

Member of the Graduate Groups in Ecology, International Agricultural Development, Horticulture and Plant Biology.
18 MS and 11 PhD students have finished under my direction over the course of my career; 3 PhD and 2 MS are in progress.

RECENT PROFESSIONAL AND PUBLIC SERVICE

Editorial Board, *Population and Environment*
Yolo County Grand Jury, 1991-92
Member of the following professional societies: American Institute of Biological Sciences, California Botanical Society, Ecological Society of America, International Society of Ecological Modelers, Sigma Xi
Chair of Committee of Science Advisors and member of the Board of Directors, San Francisco Estuary Institute.
Member of Science Review Committee, Regional Wetlands Goals Project, San Francisco Estuary Institute.

RESEARCH INTERESTS

My principal activities fall in the following areas:

* The theory and practice of ecological modeling.
* Management-oriented simulation of rice-weed interactions, with special respect to competition for light. Projects in this area are in progress in California and tropical Asia.
* Ecology and simulation of tidal salt marshes and their inhabitants. Current work is focussed on California clapper rails in the San Francisco Estuary, and their relative dependence upon stream evolution and the vegetation.
* Tidal marsh landscape dynamics of the San Francisco Estuary.

RECENT PUBLICATIONS

Foin, T. C., E. J. Garcia, R. E. Gill, S. D. Culberson, and J. N. Collins. 1997. Recovery strategies for the California clapper rail (*Rallus longirostris obsoletus*) in the heavily-urbanized San Francisco estuarine ecosystem. Landcape and Urban Planning 38:229-243.

Foin, T. C., S. P. D. Riley, A. L. Pawley, D. R. Ayres, T. M. Carlsen, P. J. Hodum, and P. V. Switzer. 1998. Improving recovery planning for the conservation of threatened and endangered taxa. Bioscience 48: 177-184.

Caton, B. P., T. C. Foin, K. D. Gibson, and J. E. Hill. 1998.A temperature-based model of direct-water seeded rice (*Oryza sativa*) stand establishment in California. Agricultural and Forest Meterology 90: 91-102..

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Strange, E. L. and T. C. Foin. 1999. Interaction of physical and biological processes in the assembly of stream fish communities. Pp. 311-337 in: Ecological Assembly Rules: perspectives, advances, retreats. (E. Weiher and P. A. Keddy, eds.) 1999. Cambridge University Press.

Caton, B. P., T. C. Foin, and J. E. Hill. 1999. A plant growth model for integrated weed management in direct-seeded rice. III. Interspecific competition for light. Field Crops Research 63: 47-61.

Sanderson, E. W., S. L. Ustin, and T. C. Foin. 2000. The influence of tidal channels on salt marsh vegetation. *Plant Ecology* 146: 29-41.

Foin, T. C. 2000. One for models, and models for all. Review of *An Illustrated Guide to Theoretical Ecology*. Conserv. Biol. 14: 1214-1215.

Gibson, K.D., J.E. Hill, T.C. Foin, B.P. Caton, and A.J. Fischer, 2001. Cultivar interference with the growth of watergrass (*Echinochloa* species) in water-seeded rice. *Agronomy Journal* 93: 326-332.

Gibson, K. D., A. J. Fischer and T. C. Foin. 2001. Shading and the growth and photosynthetic responses of *Ammannia coccinea*. *Weed Research* 41: 59-67.

Caton, B. P., A. M. Mortimer, T. C. Foin, J. E. Hill, K. D. Gibson, and A. J. Fischer, 2001. Weed morphology effects on competitiveness for light in direct-seeded rice. *Weed Research* 41: 155-163.

Gibson, K. D., J. L. Breen, J. E. Hill, B. P. Caton, and T. C. Foin. 2001. California arrowhead (*Sagittaria montevidensis*) is a weak competitor in water-seeded rice (*Oryza sativa*). *Weed Science* 49: 381-384.
Sanderson, E. W., T. C. Foin, and S. L. Ustin. 2001. A simple empirical model of salt marsh plant spatial distributions with respect to tidal channel networks. *Ecological Modelling* 139: 293-307.

IN PRESS

Culberson, S. D., T. C. Foin, and E. W. Sanderson. 2000. Vegetation and tidal marsh hydrology of three marshes within the San Francisco Bay/Delta estuary, CA, USA. *Proceedings of the 16th Annual Conference, Society of Wetlands Scientists, Quebec City.*
Caton, B. P., K. D. Gibson, T. C. Foin, and J. E. Hill, 2001. Evaluating the potential contribution of simulation models to the identification of competitive crop traits. *Field Crops Research.*
Moyle, P. B., R. D. Baxter, T. Sommer, T. C. Foin, and R. R. Abbott. Sacramento splittail white paper.

SUBMITTED

Foin, T. C., C. M. Efferson, L. M. Veilleux, R. O. Spenst, M. F. Coe, and J. D. Ficker. Predicting invasion potential of a major predator: northern pike (*Esox lucius*) in California. *Biological Invasions.*
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Blank, R. and Young, J. A. 1997. *Lepidium latifolium*: Influences on soil properties, rates of spread, and competitive stature. Pages 69-80 in J.H. Brock, M. Wade, P. Pysek and D Green, eds., Plant Invasions: Studies from North America and Europe. Backhuys Publishers, Leiden, the Netherlands.
Callaway, J. C., J. B. Zedler, and D. L. Ross. 1997. Using tidal salt marsh mescosms to aid wetland restoration. Restoration Ecol. 5: 135-146.
Chen, H., R.G. Qualls, G.C. Miller. 2001. Adaptive responses of *Lepidium latifolium* toto soil flooding: biomass allocation, adventitious rooting, aerenchyma formation and ethylene production. Plant Physiology. Submitted.
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Invasion dynamics of perennial pepperweed, Lepidium latifolium, and their consequences for protection of natural and restored wetlands in the San Francisco Estuary

Project Information

1. **Proposal Title:**

   Invasion dynamics of perennial pepperweed, Lepidium latifolium, and their consequences for protection of natural and restored wetlands in the San Francisco Estuary

2. **Proposal applicants:**

   Theodore Foin, University of California, Davis

3. **Corresponding Contact Person:**

   Ahmad Hakim-Elahi
   University of California, Davis
   Director of Sponsored Programs Office of Research, 118 Everson Hall UC Davis 1 Shields Avenue Davis CA 95616-8671
   530 752-6933
   jmorell@ucdavis.edu

4. **Project Keywords:**

   Nonnative Invasive Species
   Wetlands Ecology
   Wetlands, Tidal

5. **Type of project:**

   Research

6. **Does the project involve land acquisition, either in fee or through a conservation easement?**

   No

7. **Topic Area**:

   Non-Native Invasive Species

8. **Type of applicant:**

   University

9. **Location - GIS coordinates:**

Latitude: 38.118

Longitude: 122.174

Datum:

Describe project location using information such as water bodies, river miles, road intersections, landmarks, and size in acres.

Tidal marsh habitat from Petaluma Marsh in western San Pablo Bay area eastward to Decker Island in the lower Sacramento-San Joaquin Delta.

10. **Location - Ecozone:**

    1.4 Central and West Delta, 2.1 Suisun Bay & Marsh, 2.2 Napa River, 2.4 Petaluma River, Code 15: Landscape

11. **Location - County:**

    Napa, Solano, Sonoma

12. **Location - City:**

    Does your project fall within a city jurisdiction?

    No

13. **Location - Tribal Lands:**

    Does your project fall on or adjacent to tribal lands?

    No

14. **Location - Congressional District:**

    7th

15. **Location:**

    California State Senate District Number: 4th

    California Assembly District Number: 8th

16. **How many years of funding are you requesting?**

    3

17. **Requested Funds:**
    a) Are your overhead rates different depending on whether funds are state or federal?

       Yes

If yes, list the different overhead rates and total requested funds:

State Overhead Rate:	10%
Total State Funds:	113793.78
Federal Overhead Rate:	48.5%
Total Federal Funds:	152271.60

b) Do you have cost share partners already identified?

No

c) Do you have potential cost share partners?

No

d) Are you specifically seeking non-federal cost share funds through this solicitation?

No

If the total non-federal cost share funds requested above does not match the total state funds requested in 17a, please explain the difference:

18. **Is this proposal for next-phase funding of an ongoing project funded by CALFED?**

No

Have you previously received funding from CALFED for other projects not listed above?

Yes

If yes, identify project number(s), title(s) and CALFED program.

not assigned	**splittail simulation model**	**Lead Scientist's Funds**

19. **Is this proposal for next-phase funding of an ongoing project funded by CVPIA?**

No

Have you previously received funding from CVPIA for other projects not listed above?

No

20. **Is this proposal for next-phase funding of an ongoing project funded by an entity other than CALFED or CVPIA?**

Yes

If yes, identify project number(s), title(s) and funding source.

R/CZ-154 Tidal Marsh Ecology California Sea Grant

Please list suggested reviewers for your proposal. (optional)

21. **Comments:**

budget total is based on 100% state funds with 10% overhead

Environmental Compliance Checklist

<u>Invasion dynamics of perennial pepperweed, Lepidium latifolium, and their consequences for protection of natural and restored wetlands in the San Francisco Estuary</u>

1. **CEQA or NEPA Compliance**
   a) Will this project require compliance with CEQA?

      No
   b) Will this project require compliance with NEPA?

      No
   c) If neither CEQA or NEPA compliance is required, please explain why compliance is not required for the actions in this proposal.

      Project is experimental research to be done in a laboratory setting., except for final testing phase, which will be part of other projects under whose clearance we should be included.

2. **If the project will require CEQA and/or NEPA compliance, identify the lead agency(ies).** *If not applicable, put "None".*

   <u>CEQA Lead Agency:</u>
   <u>NEPA Lead Agency (or co-lead:)</u>
   <u>NEPA Co-Lead Agency (if applicable):</u>

3. **Please check which type of CEQA/NEPA documentation is anticipated.**

   CEQA
   -Categorical Exemption
   -Negative Declaration or Mitigated Negative Declaration
   -EIR
   Xnone

   NEPA
   -Categorical Exclusion
   -Environmental Assessment/FONSI
   -EIS
   Xnone

   If you anticipate relying on either the Categorical Exemption or Categorical Exclusion for this project, please specifically identify the exemption and/or exclusion that you believe covers this project.

4. **CEQA/NEPA Process**
   a) Is the CEQA/NEPA process complete?

      Not Applicable

b) If the CEQA/NEPA document has been completed, please list document name(s):

5. **Environmental Permitting and Approvals** (*If a permit is not required, leave both Required? and Obtained? check boxes blank.*)

LOCAL PERMITS AND APPROVALS

Conditional use permit

Variance

Subdivision Map Act

Grading Permit

General Plan Amendment

Specific Plan Approval

Rezone

Williamson Act Contract Cancellation

Other

STATE PERMITS AND APPROVALS

Scientific Collecting Permit Required, Obtained

CESA Compliance: 2081

CESA Compliance: NCCP

1601/03

CWA 401 certification

Coastal Development Permit

Reclamation Board Approval

Notification of DPC or BCDC

Other

FEDERAL PERMITS AND APPROVALS

ESA Compliance Section 7 Consultation

ESA Compliance Section 10 Permit Required

Rivers and Harbors Act

CWA 404

Other

PERMISSION TO ACCESS PROPERTY

Permission to access city, county or other local agency land. Agency Name:	
Permission to access state land. Agency Name: Cal Fish and Game	Required, Obtained
Permission to access federal land. Agency Name:	
Permission to access private land. Landowner Name: Solano Land Trust	Required, Obtained

6. **Comments.**

Land Use Checklist

Invasion dynamics of perennial pepperweed, Lepidium latifolium, and their consequences for protection of natural and restored wetlands in the San Francisco Estuary

1. **Does the project involve land acquisition, either in fee or through a conservation easement?**

   No

2. **Will the applicant require access across public or private property that the applicant does not own to accomplish the activities in the proposal?**

   Yes

3. **Do the actions in the proposal involve physical changes in the land use?**

   No

   If you answered no to #3, explain what type of actions are involved in the proposal (i.e., research only, planning only).

   research only. There is a possibler exception in field verification, if physical grading is required. The lead agency will acquire the necessary permits.

4. **Comments.**

Conflict of Interest Checklist

<u>Invasion dynamics of perennial pepperweed, Lepidium latifolium, and their consequences for protection of natural and restored wetlands in the San Francisco Estuary</u>

Please list below the full names and organizations of all individuals in the following categories:

- Applicants listed in the proposal who wrote the proposal, will be performing the tasks listed in the proposal or who will benefit financially if the proposal is funded.
- Subcontractors listed in the proposal who will perform some tasks listed in the proposal and will benefit financially if the proposal is funded.
- Individuals not listed in the proposal who helped with proposal development, for example by reviewing drafts, or by providing critical suggestions or ideas contained within the proposal.

The information provided on this form will be used to select appropriate and unbiased reviewers for your proposal.

Applicant(s):

Theodore Foin, University of California, Davis

Subcontractor(s):

Are specific subcontractors identified in this proposal? No

Helped with proposal development:

Are there persons who helped with proposal development?

No

Comments:

Budget Summary

<u>Invasion dynamics of perennial pepperweed, Lepidium latifolium, and their consequences for protection of natural and restored wetlands in the San Francisco Estuary</u>

Please provide a detailed budget for each year of requested funds, indicating on the form whether the indirect costs are based on the Federal overhead rate, State overhead rate, or are independent of fund source.

<u>State Funds</u>

Year 1												
Task No.	**Task Description**	**Direct Labor Hours**	**Salary *(per year)***	**Benefits *(per year)***	**Travel**	**Supplies & Expendables**	**Services or Consultants**	**Equipment**	**Other Direct Costs**	**Total Direct Costs**	**Indirect Costs**	**Total Cost**
1	CCA		10007.25	300.22	3450	3000			6000	22757.47	3617.78	26375.25
1	CCA	300	2100	63						2163.0		2163.00
2	seed expt		8187.3	245.62		2000				10432.92		10432.92
2	seed expt	80	824							824.0		824.00
		380	21118.55	608.84	3450.00	5000.00	0.00	0.00	6000.00	36177.39	3617.78	39795.17

Year 2												
Task No.	**Task Description**	**Direct Labor Hours**	**Salary *(per year)***	**Benefits *(per year)***	**Travel**	**Supplies & Expendables**	**Services or Consultants**	**Equipment**	**Other Direct Costs**	**Total Direct Costs**	**Indirect Costs**	**Total Cost**
2	growth expt		19104.75	573.14	2000	1500			5072.55	28250.44		28250.44
2	growth expt	200	1470	44.1						1514.1		1514.10
2	growth expt	160	1730.4							1730.4	3149.49	4879.89
		360	22305.15	617.24	2000.00	1500.00	0.00	0.00	5072.55	31494.94	3149.49	34644.43

Year 3												
Task No.	**Task Description**	**Direct Labor Hours**	**Salary *(per year)***	**Benefits *(per year)***	**Travel**	**Supplies & Expendables**	**Services or Consultants**	**Equipment**	**Other Direct Costs**	**Total Direct Costs**	**Indirect Costs**	**Total Cost**
3	mesocosm exp		20014.5	600.44	2000	1500			5314.1	29429.04	3486.74	32915.78
3	mesocosm exp	200	1540	46.2						1586.2		1586.20
3	mesocosm exp	200	2266							2266.0		2266.00
3	field test	200	1540	46.2						1586.2		1586.20
		600	25360.50	692.84	2000.00	1500.00	0.00	0.00	5314.10	34867.44	3486.74	38354.18

Grand Total=<u>112793.78</u>

Comments.

Budget Justification

Invasion dynamics of perennial pepperweed, Lepidium latifolium, and their consequences for protection of natural and restored wetlands in the San Francisco Estuary

Direct Labor Hours. Provide estimated hours proposed for each individual.

The Research Assistant associated with this proposal has her annual salary (at UC scale) listed without regard to hours, except that tasks 1 and 2 in yr 1 are split. The salary is calculated at 9 months (academic year) @ 50% time and 3 months @ 100% time. Undergraduate assistants have been calculated as two persons. The hours listed can be divided by 2 to get the individual total. Similarly, casual labor is based on two persons and can be divided in the same way.

Salary. Provide estimated rate of compensation proposed for each individual.

Research Assistants are $1213 per month @50% and 2426/month full time. Student Assistants are 7.00 per hr. Casual Labor is $10.30 per hour. 5% COLA has been included for each year.

Benefits. Provide the overall benefit rate applicable to each category of employee proposed in the project.

The benefit rate for students is 3%. Casual labor has no benefits associated with the salary. The Research Assistant is due university fee remission for each quarter enrolled. This is provided for in the other direct cost category.

Travel. Provide purpose and estimate costs for all non-local travel.

Most of the travel is for local travel, either through vehicle reimbursement or rental of a university vehicle. One conference meeting per year is included, assuming out of state locations but not international.

Supplies & Expendables. Indicate separately the amounts proposed for office, laboratory, computing, and field supplies.

All supplies are directly associated with the proect, including equipment in the first year that does not meet the definition of 5K per item. Computing and office supplies are being paid for by faculty funds. These include new balances, pH meter, GPS locator, and an outboard motor and boat trailer.

Services or Consultants. Identify the specific tasks for which these services would be used. Estimate amount of time required and the hourly or daily rate.

not applicable

Equipment. Identify non-expendable personal property having a useful life of more than one (1) year and an acquisition cost of more than $5,000 per unit. If fabrication of equipment is proposed, list parts and materials required for each, and show costs separately from the other items.

not applicable

Project Management. Describe the specific costs associated with insuring accomplishment of a specific project, such as inspection of work in progress, validation of costs, report preparation, giving presentatons, reponse to project specific questions and necessary costs directly associated with specific project oversight.

Publication and conference costs are the only ones included in this budget. All administrative costs are included in overhead.

Other Direct Costs. Provide any other direct costs not already covered.

Each year includes the fee remission with an anticipated 5% inflation factor. The first year includes publication costs (figures and page charges, reprints).

Indirect Costs. Explain what is encompassed in the overhead rate (indirect costs). Overhead should include costs associated with general office requirements such as rent, phones, furniture, general office staff, etc., generally distributed by a predetermined percentage (or surcharge) of specific costs.

Overhead is 10% of total direct costs by negotiation with the State of California and CALFED.

Executive Summary

Invasion dynamics of perennial pepperweed, Lepidium latifolium, and their consequences for protection of natural and restored wetlands in the San Francisco Estuary

The relatively recent introductions of two highly successful exotics, Spartina alterniflora and Lepidium latifolium, threaten the structure and functional integrity of those remaining Bay-Delta wetlands and may have a devastating impact on marsh restoration. While Spartina alterniflora is the subject of continuing research, comparatively little is known about Lepidium latifolium in light of its potential impact on the Bay-Delta system. L. latifolium has been shown to invade riparian corridors, freshwater, brackish, and saline tidal wetlands successfully. The objective of this proposal is to determine the characteristics of Lepidium latifolium that facilitate its colonization and of the tidal marshes it invades. This research is expected to reveal demographic weaknesses, which when translated into restoration policy, would help check the establishment of Lepidium, enhancing the protection of natural wetlands and preventing its invasion into restored wetlands. The proposed research focuses on the determination of life history and population biology; the combination of reproductive life history strategies and environmental characteristics associated with L. latifolium invasibility; and testing the emerging model of L. latifolium - environment interactions on simulated tidal marshes, with field verification in San Francisco Bay and Suisun Bay sites. The proposed research should enhance the development of a control strategy for one of the areas most noxious wetland weeds. Eradication of this species is extremely difficult or impossible once it is well-established; our expected control strategy will focus on prevention of spread, reduction of threat to restored areas, and mitigation of negative impacts. In addition, this research will provide improved mechanistic understanding of how L. latifolium successfully invades tidal marshes, the environmental determinants of its success and most effective control strategies. By so doing, it will address one of the most serious problems identified in the CALFED Ecosystem Restoration Plan. The research protocol could serve as a model for other exotic wetland plant invaders and so its benefits may reach beyond Lepidium itself..

Proposal

University of California, Davis

Invasion dynamics of perennial pepperweed, Lepidium latifolium, and their consequences for protection of natural and restored wetlands in the San Francisco Estuary

Theodore Foin, University of California, Davis

PROPOSAL TITLE: **INVASION DYNAMICS OF PERENNIAL PEPPERWEED, *LEPIDIUM LATIFOLIUM*, AND THEIR CONSEQUENCES FOR PROTECTION OF NATURAL AND RESTORED WETLANDS IN THE SAN FRANCISCO ESTUARY**

Principal Investigator: Theodore C. Foin
University of California, Davis

Proposal Starting Date: 1 January 2002

Period of Support: 3 years

Budget Requested: $113793.78

THE PROBLEM: MINIMIZING INVASIVE SPECIES IN RESTORING TIDAL MARSHES IN THE SAN FRANCISCO ESTUARY

Successful wetlands restoration is one of the core goals of the CALFED program. Although many specific restoration programs have been proposed and funded, the need for scientifically rigorous experiments with repeatable results and adaptive responses built-in remains a major concern of the agency. One of the most serious problems affecting restoration success is the distinct possibility that a restored marsh might be dominated by an undesirable invasive species, an outcome that might be worse than the degraded marsh it was intended to replace. Some marsh biologists have even expressed concern that marsh restoration should not proceed without an effective program to prevent invasion by aggressive exotics (D. R. Ayres, personal communication).

The threat of invasive plants to the tidal marshes of the lower Delta and San Pablo Bay regions of the San Francisco Estuary is most certain for two species. One is smooth cordgrass (*Spartina alterniflora*), a serious problem in fully tidal salt marshes of San Francisco Bay. Don Strong and colleagues are currently working on the former, mostly in San Francisco Bay but also in Washington. The other species is perennial pepperweed, *Lepidium latifolium*, a tall forb which occurs throughout the Estuary, in alkali sinks, in cool deserts and even annual and perennial grasslands, through which it spreads with ease (Mark Renz, unpublished research).

Lepidium latifolium has received much less attention but it may actually be the more dangerous of the two species. It has vital attributes and a life history that are characteristic of prototypic exotics (Rejmanek, 1996). It is a member of the mustard family (Cruciferae), a family known for having many weedy species, numerous small and easily dispersed seed, and ability to reach large sizes. *Lepidium latifolium* shares these family traits; in addition, it is large (reaching 1 m or more in height) and highly fertile (freely produces lateral branches, each with numerous flowers and small, easily dispersed seed). *L. latifolium* grows fast and has a large, aggressive root system, which enables it to compete effectively with other perennials while retaining the reproductive effort of

annuals, It reproduces by both sexual and vegetative means (Trumbo, 1994). Furthermore, *L. latifolium* may compete with other species by pumping salt ions from deep in the soil profile to the surface, making the immediate surroundings less suitable for other species (Blank and Young, 1997).

One known weakness in the biology of *L. latifolium* is that it is not effective in colonizing the upper marsh. It has some ability to tolerate or survive saturated conditions and the elevated soil salinities found there, but is not known to grow well under these conditions (Chen et al, 2001; May, 1995; Young and Turner, 1995). Consequently, *Lepidium latifolium* poses its gravest threat to the streamside zone, which generally has moderated salinity, abundant water, and better drainage. Despite its relatively recent introduction into Pacific tidal marshes, *L. latifolium* has spread quickly along stream courses, and is considered a serious invader of this zone from full salt marshes upriver to muted tidal and freshwater marshes. In our opinion, its aggressive growth, euryhaline tolerance, persistence in face of attempts to eradicate it and its potential for altering the functional role of estuarine vegetation through competitive displacement make it a very serious threat to marsh restoration programs.

PROPOSAL JUSTIFICATION

Although we naturally focus on invasive species with greater economic or ecological impact, there is little conceptual distinction between biological invaders and recolonization by native species. Colonization by any species is the joint product of site invasibility and those vital attributes of the potential colonist that facilitate its dispersal and colonization. This proposal is organized around this basic principle, focusing upon the relative impact of each component of colonist demography and physiological requirements and environmental resistance.

Prior research with *L. latifolium* suggests 1) that seed dispersal is not limiting; 2) that once plants produce large rhizomes, they cannot be easily displaced; and 3) the critical demographic phase is in establishment and maturation in the first year. Maturation is particularly important since these plants subsequently become local seed sources. Since experience shows that adequate control after establishment is at best difficult and environmentally disruptive, colonization of restoration sites by *Lepidium* must be prevented by some combination of increased site resistance and exploitation of demographic bottlenecks. We seek to estimate the risk of *Lepidium* establishment by measuring site invasibility and defining its colonization strategies from its biological and ecological traits. We can then combine both types of information to test the invasion success by *L. latifolium* in simulated marsh stands and environmental conditions. The goal of this research is to minimize the spread of pepperweed by elucidating the conditions under which it is favored and by potentially providing the opportunity to exploit weaknesses in the life history and population biology of *L. latifolium* to control its spread throughout Estuary marshes.

Adaptive management is expected to be of less concern with this proposal than with restoration programs. Because the research is with a dangerous exotic, most of it will be in the laboratory under controlled conditions. Experiments that do not turn out as

expected are a problem of ordinary science; the adjustments are technically part of adaptive management, but the potential negative consequences are much smaller. The final field tests can fail, and lead to growth and establishment of *Lepidium* despite the design and expectations. The appropriate response under these conditions will be to destroy the *Lepidium* at the end of the first year.

OBJECTIVES OF THIS PROPOSAL

This proposal has three specific objectives.

1. To determine the properties of tidal marshes governing their invasibility by exotic species, with special regard to different positions in the wetland landscape.

2. To determine the combination of reproductive life history strategies and environmental characteristics that are associated with *Lepidium latifolium* invasibility.

3. To test the emerging model of ecological influences on colonization by *Lepidium latifolium* on simulated tidal marshes.

The outcome of this project should be a much-improved picture of the requirements and responses of *Lepidium latifolium* in marsh environments, and possibly a strategy for minimizing its dispersal. As such, this research will provide the biological foundation upon which a control strategy can be built.

PROPOSED APPROACH

Objective 1. To determine the properties of tidal marshes governing their invasibility by exotic species, particularly Lepidium latifolium.

It is important to discover which attributes of tidal marshes in the San Francisco Estuary are key determinants of successful pepperweed colonization. Our previous research has shown that *L. latifolium* is largely restricted to the streamside zone in tidal marshes; often the smaller channels in the marsh are delineated by a mixture of *fringing Scirpus* spp. and *Lepidium*. Our mathematical model (developed from the conceptual model in Foin *et al.* 2000) suggests that a combination of more abundant water supply and regular flushing of salinity acts to open these sites to *Lepidium* colonization. Conversely, the upper marsh may have persistent high water levels with too highly elevated soil salinity to support *Lepidium* invasion. Thus, the principal focus of this phase of the research will be the streamside zone.

In order to elucidate environmental factors contributing to *Lepidium latifolium* invasion, canonical correspondence analysis (hereafter abbreviated to CCA) will be used to regress streamside species and sampling units against environmental factors. CCA

allows the user to compare species and distribution patterns and environmental variables in a single step by combining regression with multivariate analysis. The sampling units will consist of 1 m^2 units. The analysis will be run using *Lepidium* as an environmental factor in order to examine species correlations, and then with pepperweed grouped with the other species to affirm that salinity is the dominant gradient responsible for segregating species and to suggest other factors which may be significant determinants. Data will be collected at multiple sites along a salinity gradient ranging from full strength seawater (western San Pablo Bay sites) to fresh water (Suisun Marsh). The exact sites to be sampled will include Rush Ranch and Petaluma Marsh, plus a series of younger marshes to be chosen from sites along San Pablo Bay and others in the Suisun Marsh in Solano County. A minimum of 20-1 m^2 samples will be collected from each site. Species composition, percent cover, and several environmental variables (channel salinity, soil salinity, flooding regime interpolated from tide tables, pH, soil particle size, and percent organic matter) will be recorded for each sample. Sampling will be conducted in one short time period at each site, but can be repeated in subsequent years if the analysis requires it.

The results will be analyzed using PC-Ord (McCune, 1999) for CCA. We expect the results to confirm the hypothesis that increasing salinity is the dominant environmental factor limiting successful pepperweed invasion. This hypothesis was developed from a 2001 experiment measuring growth under different salinity and flooding conditions under controlled conditions. We next need to confirm these results in the field, with natural conditions of tidal input and soil. It will be particularly important to examine the influence of these covariates as clues to the mechanisms limiting *Lepidium*.

Objective 2. To determine the combination of reproductive life history strategies and environmental characteristics that are associated with Lepidium latifolium invasibility.

Two principal means for pepperweed dispersal (rhizome fragmentation and seed dispersal) have been documented. Field observations have shown that broken rhizomes are an important source of propagules for dispersing pepperweed (M. Renz, pers. comm.). This is a difficult mechanism to study, given the erratic dispersal of broken rhizomes and the numerous conditions that can influence their growth. The difficulty in making satisfactory experimental measurements of rhizome establishment rates is a daunting problem. We concede that rhizomes are probably important propagules, especially after a reproducing population has established either locally or at some location upstream of the site. Our best evidence of significant colonization by rhizomes may be indirect, resulting from seeing successful establishment in the field that cannot be accounted for by seedling germination and growth.

The rapid establishment of *Lepidium* across the western states suggests that seed dispersal is probably the principal means of expansion. *L. latifolium* routinely produces numerous seed, but to date the role of seed in colonization has not been quantified. The copious seed suggests that wind and animal dispersal are important mechanisms for

pepperweed colonization, at least in streamside habitats, and perhaps the most important one.

Seed dispersal and early growth. Because seed are both numerous and readily dispersed, it seems safe to assume that dispersal is not a major limiting factor on *Lepidium* invasibility, and instead concentrate upon establishment.

Experimental seeding in the field has obvious flaws and dangers, so laboratory experiments will be the principal means for assessing the reproductive strategies of *Lepidium latifolium*. This research will examine the success of reproduction from seed in relation to the nature of the stand. We propose to seed pepperweed into stands of native streamside dominants of varying densities, from bare ground to normal densities under different salinities (0, 15, 35 ppt - the range of salinities found in the streamside zone in the Estuary) in the laboratory for better control over site conditions. *L. latifolium* will be seeded into stands of native dominants (*S. acutus, S. americanus. S. maritimus*) to determine the importance of seedling survivorship to *L. latifolium* expansion. This will be a randomized complete block design with salinity assigned to the main plots and *Scirpus* cover randomly assigned within blocks. The number (estimated by weight of seed sown) of *L. latifolium* seeds will be constant across treatments. The response variable will be the estimated number of germinated seeds and number surviving to seedlings and adulthood, broken down into size groups (height <5cm, 5-30 cm, 30-60 cm, and >60 cm). There will be 8 replicates per treatment. Results will be analyzed with ANOVA and quantified by regression equations. We hypothesize that these competitive relationships, in the context of prevailing salinity conditions, will determine the rate of *Lepidium* growth and its long-term establishment.

Post-colonization growth and establishment. *Lepidium latifolium* can be expected to compete against the tules (*Scirpus* spp.) normally found in the streamside zone. The previous experiment should tell us how much tule stands can be expected to resist *Lepidium* invasion. The effect of *Lepidium* on *Scirpus* spp. is the subject of the next experiment. To assess the potential for competitive displacement of tules in tidal marshes, growth responses of *Lepidium latifolium* will be compared to three native wetland streamside dominants (the same three *Scirpus* as in the seeding experiment)across a range of salinity treatments. The experiment monitors the growth of each of the three species in growth boxes under three salinity treatments (0, 15, 35 ppt) and two flooding regimes (daily, every 4th day). The experimental design is a split plot design with salinity as the main plot, flooding regime the subplot, and species identity randomly assigned to the subplots. Plants will be propagated from root stock. There will be four replicates per treatment, and four subsamples in each sampling unit to reduce variability of root stock. The number of replicates is constrained by the number of treatments and plumbing constraints. Preliminary results from a pilot experiment done this year indicate that this is an adequate number of replicates for the variance expected. Above- and below-ground biomass will be collected at the end of the growing season. Growth response will also be monitored throughout the growing season by repeatedly measuring the growth of randomly selected stems in each experimental unit Results will be analyzed with repeated measures ANOVA.

Objective 3. To test the emerging model of ecological influences on colonization by Lepidium latifolium on simulated tidal marshes.

The results from earlier experiments will allow us to identify those species and environmental variables having the greatest effect on *Lepidium* invasion success. These results will permit us to establish stand conditions that should vary with respect to suitability for *Lepidium* seedlings. Such stands will be planted as a validation experiment, set up in mesocosms that will have simulated tidal and salinity conditions to match the combinations having the greatest effect on invasibility. The design will be a randomized complete block design with five replicates. The treatments will be selected from the series of conditions elucidated above that are most applicable to pepperweed invasion. Satisfactory rank order in invasion success will serve to test our understanding.

Successful validation will open the possibility for field tests of planting strategies that can be tested in sites being restored in the field. Although this aspect remains too preliminary to promise as a finite objective, such field experiments will be discussed in our interactions with the Simenstad-Reed-Phil Williams team and the DWR marsh restoration program, both of which will be conducting restoration programs and who have indicated their willingness to collaborate with us. Since we will not deliberately introduce *Lepidium* seed into the field, we will require sites at which pepperweed is already present in the general area. Field validation is one way to address any lingering concerns about our ability to produce satisfactory mescosms (see Callaway *et al*.1997). Whether or not field validation can be performed, we expect this proposal to identify species, planting schemes and environmental conditions which have the greatest exclusionary impact on pepperweed.

FEASIBILITY

This proposal is based on methods that have been well tested in ecology, marsh biology and the field in previous research leading up to this one. The laboratory-based and field survey elements of this proposal are demonstrably feasible and no insurmountable problems are expected to arise therein.

The final field-based tests of *Lepidium* exclusion will require permits. We hope to be included in existing or forthcoming permits at Simenstad-Reed Williams and/or DWR sites. The exact design elements cannot be specified until the laboratory results are in and analyzed, but hopefully will result in feasible restoration schemes (planting densities, species type, and predominant hydrologic-geomorphic conditions).

PERFORMANCE MEASURES

The only aspect of this proposal subject to specification of a successful performance evaluation will be the field experiment. Once the treatments are in place, the experiment will have to be routinely monitored for *Lepidium* colonization, most likely over a two-year period to allow for two germination and growth cycles. *Lepidium*

seedlings appearing in the site are not sufficient to judge the experiment a failure; *Lepidium* must grow and produce seed to meet this condition. If *Lepidium* seed are locally available but there is no successful colonization within the two years, the experiment will be deemed successful.

DATA HANDLING AND STORAGE

All data will be stored in a data vault system maintained and backed up in the Computing Facility of the Department of Agronomy and Range Science, University of California, Davis. Results will be posted to our website at agronomy.ucdavis.edu.

OUTCOMES AND EXPECTED BENEFITS OF THIS RESEARCH

If the research progresses as outlined, we think a testable *Lepidium* prevention strategy will emerge before the end of the project term. By elucidating the conditions under which pepperweed is favored and by potentially providing the opportunity to exploit vulnerabilities in its life history and population biology to control its spread, we should be able to develop an improved picture of the requirements and responses of *Lepidium latifolium* in marsh environments, and possibly a strategy for minimizing its dispersal. This can be further tested in the field or implemented without increasing the risk of *Lepidium* invasion.

We shall participate in future CALFED science conferences, publish in regular journals, and perhaps produce a manual on planting and environmental management that minimizes the risk of *Lepidium* invasion.

WORK SCHEDULE

Objective	Task	Timeframe
1	field survey using CCA	June-September 2002
2	experimental seeding into *Scirpus* spp.	May-October 2002
2	growth in competition with *Scirpus* spp.	May-October 2003
3	mesocosm tests in simulated streamside stands	February-September 2004
3	field verification	February 2005-October 2006

The off-season (November-February) is reserved for data analysis. Above-ground material will be collected from Rush Ranch to support a regression of plant height against biomass for each species. In the fall of 2001, native streamside dominants will be placed into growth chambers to grow them out for the stands of the seeding

experiment beginning in the spring, 2002. We will collect data on species and environmental factors for the CCA in the summer of 2002. In the spring of 2004, the mesocosm experiments will begin and will continue through the fall. Technically, field verification proceeds beyond the term of this proposal, although planting of experimental stands will likely be completed in 2004. Details of monitoring will continue, but exact arrangements will have to be made later.

Applicability to ERP Goals

The four ERP goals applicable to this proposal are:

Goal 1: *protection and restoration of native biotic communities*

Goal 2: *Rehabilitate natural aquatic and adjacent plant communities to support native members of those areas*

Goal 4: *Protect and/or restore functional habitat types in the Bay-Delta estuary and its watershed for ecological and public values such as supporting species and biotic communities, ecological processes, recreation, scientific research, and aesthetics, including restoration of tidal marsh, sloughs, seasonal and riparian wetlands and protecting tracts of existing high quality wetland*

Goal 5: *Prevent establishment of additional non-native invasive species and reduce the negative ecological and economic impacts of established non-natives in the Bay-Delta estuary and its watershed, including where possible limiting spread or eradication of non-natives*

The proposed research will directly address each of these four goals. *Lepidium latifolium* is specifically identified as a major problem in the Bay-Delta estuary and its watershed. This species poses a grave threat to remaining wetlands in the Bay-Delta system and to proposed restoration projects because it is highly successful across a wide spectrum of wetland habitats. This research seeks to provide a mechanistic understanding of the way in which *L. latifolium* is able to invade a wetland site with respect to the invader and the environmental characteristics of the site. Development of a successful control protocol would help protect remaining intact systems; provide a means for reducing its spread; and prevent the invasion of *Lepidium latifolium* into restoring sites.

PREVIOUS CALFED SUPPORT

I have support from the Science Advisors funds (30K) to support mathematical modeling population dynamics of splittail. *Pogonicthys macrolepidopterus*. This work is completely separate from this proposal.

SYSTEM-WIDE ECOSYSTEM BENEFITS

This proposal seeks to develop and test the adequacy of a protocol to address the invasibility of tidal marshes, and secondarily to find management schemes which

maximize exclusion of pepperweed. To the extent to which this proposal is productive, we can expect to improve restoration by excluding *Lepidium*, and perhaps develop a protocol that can be used for a larger number of invasive plant species.

QUALIFICATIONS

ABBREVIATED CURRICULUM VITAE
THEODORE C. FOIN
Updated 9 October 2000

EDUCATIONAL SUMMARY

A.B., Biological Sciences, Stanford University, 1962
Ph.D., Zoology (Ecology), University of North Carolina, Chapel Hill, 1967

CURRENT ACADEMIC POSITION

Professor
Department of Agronomy and Range Science
University of California, Davis 95616
1998-Present

ROUTINE TEACHING RESPONSIBILITIES

ASE 121. Systems Analysis in Agriculture and Resource Management
Ecology 200B. Principles and Application of Ecological Theory.
Ecology 201. Modeling Ecosystems and Landscapes

GRADUATE EDUCATION

Member of the Graduate Groups in Ecology, International Agricultural Development, Horticulture and Plant Biology.
18 MS and 11 PhD students have finished under my direction over the course of my career; 3 PhD and 2 MS are in progress.

RECENT PROFESSIONAL AND PUBLIC SERVICE

Editorial Board, *Population and Environment*
Yolo County Grand Jury, 1991-92
Member of the following professional societies: American Institute of Biological Sciences, California Botanical Society, Ecological Society of America, International Society of Ecological Modelers, Sigma Xi
Chair of Committee of Science Advisors and member of the Board of Directors, San Francisco Estuary Institute.
Member of Science Review Committee, Regional Wetlands Goals Project, San Francisco Estuary Institute.

RESEARCH INTERESTS

My principal activities fall in the following areas:

* The theory and practice of ecological modeling.
* Management-oriented simulation of rice-weed interactions, with special respect to competition for light. Projects in this area are in progress in California and tropical Asia.
* Ecology and simulation of tidal salt marshes and their inhabitants. Current work is focussed on California clapper rails in the San Francisco Estuary, and their relative dependence upon stream evolution and the vegetation.
* Tidal marsh landscape dynamics of the San Francisco Estuary.

RECENT PUBLICATIONS

Foin, T. C., E. J. Garcia, R. E. Gill, S. D. Culberson, and J. N. Collins. 1997. Recovery strategies for the California clapper rail (*Rallus longirostris obsoletus*) in the heavily-urbanized San Francisco estuarine ecosystem. Landcape and Urban Planning 38:229-243.

Foin, T. C., S. P. D. Riley, A. L. Pawley, D. R. Ayres, T. M. Carlsen, P. J. Hodum, and P. V. Switzer. 1998. Improving recovery planning for the conservation of threatened and endangered taxa. Bioscience 48: 177-184.

Caton, B. P., T. C. Foin, K. D. Gibson, and J. E. Hill. 1998.A temperature-based model of direct-water seeded rice (*Oryza sativa*) stand establishment in California. Agricultural and Forest Meterology 90: 91-102..

Gibson, K. D., T. C. Foin, and J. E. Hill. 1999. The relative importance of root and shoot competition between water-seeded rice and watergrass. Weed Research 39: 181-190.

Caton, B. P., T. C. Foin, and J. E. Hill. 1999. A plant growth model for integrated weed management in direct-seeded rice. I. Development, parameterization, and monoculture growth. Field Crops Research 62: 129-143.

Caton, B. P., T. C. Foin, and J. E. Hill. 1999. A plant growth model for integrated weed management in direct-seeded rice. II. Validation testing of water-depth effects and monoculture growth. Field Crops Research 62: 145-155.

Strange, E. L. and T. C. Foin. 1999. Interaction of physical and biological processes in the assembly of stream fish communities. Pp. 311-337 in: Ecological Assembly Rules: perspectives, advances, retreats. (E. Weiher and P. A. Keddy, eds.) 1999. Cambridge University Press.

Caton, B. P., T. C. Foin, and J. E. Hill. 1999. A plant growth model for integrated weed management in direct-seeded rice. III. Interspecific competition for light. Field Crops Research 63: 47-61.

Sanderson, E. W., S. L. Ustin, and T. C. Foin. 2000. The influence of tidal channels on salt marsh vegetation. *Plant Ecology* 146: 29-41.

Foin, T. C. 2000. One for models, and models for all. Review of *An Illustrated Guide to Theoretical Ecology*. Conserv. Biol. 14: 1214-1215.

Gibson, K.D., J.E. Hill, T.C. Foin, B.P. Caton, and A.J. Fischer, 2001. Cultivar interference with the growth of watergrass (*Echinochloa* species) in water-seeded rice. *Agronomy Journal* 93: 326-332.

Gibson, K. D., A. J. Fischer and T. C. Foin. 2001. Shading and the growth and photosynthetic responses of *Ammannia coccinea*. *Weed Research* 41: 59-67.

Caton, B. P., A. M. Mortimer, T. C. Foin, J. E. Hill, K. D. Gibson, and A. J. Fischer, 2001. Weed morphology effects on competitiveness for light in direct-seeded rice. *Weed Research* 41: 155-163.

Gibson, K. D., J. L. Breen, J. E. Hill, B. P. Caton, and T. C. Foin. 2001. California arrowhead (*Sagittaria montevidensis*) is a weak competitor in water-seeded rice (*Oryza sativa*). *Weed Science* 49: 381-384.
Sanderson, E. W., T. C. Foin, and S. L. Ustin. 2001. A simple empirical model of salt marsh plant spatial distributions with respect to tidal channel networks. *Ecological Modelling* 139: 293-307.

IN PRESS

Culberson, S. D., T. C. Foin, and E. W. Sanderson. 2000. Vegetation and tidal marsh hydrology of three marshes within the San Francisco Bay/Delta estuary, CA, USA. *Proceedings of the 16th Annual Conference, Society of Wetlands Scientists, Quebec City.*
Caton, B. P., K. D. Gibson, T. C. Foin, and J. E. Hill, 2001. Evaluating the potential contribution of simulation models to the identification of competitive crop traits. *Field Crops Research.*
Moyle, P. B., R. D. Baxter, T. Sommer, T. C. Foin, and R. R. Abbott. Sacramento splittail white paper.

SUBMITTED

Foin, T. C., C. M. Efferson, L. M. Veilleux, R. O. Spenst, M. F. Coe, and J. D. Ficker. Predicting invasion potential of a major predator: northern pike (*Esox lucius*) in California. *Biological Invasions.*
Caton, B. P., A. M. Mortimer, J. E. Hill, and T. C. Foin. 2001. Water depth effects on the growth and root-shoot dynamics of two rice varieties and two *Echinochloa* spp. *Field Crops Research.*

LITERATURE CITED

Blank, R. and Young, J. A. 1997. *Lepidium latifolium*: Influences on soil properties, rates of spread, and competitive stature. Pages 69-80 in J.H. Brock, M. Wade, P. Pysek and D Green, eds., Plant Invasions: Studies from North America and Europe. Backhuys Publishers, Leiden, the Netherlands.
Callaway, J. C., J. B. Zedler, and D. L. Ross. 1997. Using tidal salt marsh mescosms to aid wetland restoration. Restoration Ecol. 5: 135-146.
Chen, H., R.G. Qualls, G.C. Miller. 2001. Adaptive responses of *Lepidium latifolium* toto soil flooding: biomass allocation, adventitious rooting, aerenchyma formation and ethylene production. Plant Physiology. Submitted.
Culberson, S.D. 2001. The interaction of physical and biological determinants producing vegetation zonation in tidal marshes of the San Francisco Bay/Delta, California, USA. Unpublished Ph.D. Dissertation, University of California, Davis. 148 pp.
Foin T. C., S. D. Culberson, and M. R. Pakenham-Walsh. 2000. A productivity-based model of tidal hydrology influence on marsh vegetation. Abstracts of the CALFED Science Conference, p. 175.

May, M. 1995. *Lepidium latifolium* L. in the San Francisco Estuary. 16 pp.
McCune, B. 1999. PC Ord Version 4. Multivariate analysis of ecological data. MJM Software Design.
Rejmanek, M. 1996. A theory of seed plant invasiveness: the first sketch. Biological Conservation 78: 171-181.
Trumbo, J., 1994. Perennial pepperweed: a threat to wildland areas. Cal EPPC News 2: 4-5.
Young, J.A. and C. Turner, 1995. *Lepidium latifolium* L. in California. Cal EPPC News 3: 4-5.

Executive Summary

INVASION DYNAMICS OF PERENNIAL PEPPERWEED, *LEPIDIUM LATIFOLIUM*, AND THEIR CONSEQUENCES FOR PROTECTION OF WETLANDS IN THE SAN FRANCISCO ESTUARY

The invasive composite, *Lepidium latifolium* (perennial pepperweed), is increasingly recognized as one of the most successful invaders in California ecosystems. Perennial pepperweed has demographic and dispersal characteristics that underscore its successful colonization and dominance of multiple environments. As such, *L. latifolium* represents a threat to many of the tidal wetlands in the San Francisco Estuary, especially those relict wetlands currently slated for restoration.

The objective of this proposal is to determine the demographic and ecological properties which are responsible for its success, in order to support the development of strategies to exclude or control the species. The specific research in this proposal has been designed to test several hypotheses. A field sampling program using correlation analysis should test the ability of elevated salinity and persistent soil saturation to account for the distribution and abundance of *L. latifolium* a range of tidal marshes throughout the Estuary. Previous research suggests these factors are important in the distribution of other tidal marsh species. Field measurement of size-related seed production and wind dispersal of seed will allow measurement of propagule production and dispersal by wind. A laboratory-based experimental study of pepperweed colonization into planted stands of marsh dominants will measure the degree of competitive suppression by different native species, and in conjunction with CCA will test correspondence between competitive results and field distribution. The field herbicide trials will extend earlier experiments into the estuarine environment to examine the long-term impact on pepperweed suppression and the recovery of native plants.

The control of exotics is one of the most important elements in the ERP. We expect the proposed research to contribute an improved, mechanistic, understanding of how *Lepidium latifolium* successfully invades tidal marshes, the environmental determinants of its success, and element constituting effective control strategies.

Invasion dynamics of perennial pepperweed, Lepidium latifolium, and their consequences for protection of natural and restored wetlands in the San Francisco Estuary

Project Information

1. **Proposal Title:**

   Invasion dynamics of perennial pepperweed, Lepidium latifolium, and their consequences for protection of natural and restored wetlands in the San Francisco Estuary

2. **Proposal applicants:**

   Theodore Foin, University of California, Davis

3. **Corresponding Contact Person:**

   Ahmad Hakim-Elahi
   University of California, Davis
   Director of Sponsored Programs Office of Research, 118 Everson Hall UC Davis 1 Shields Avenue Davis CA 95616-8671
   530 752-6933
   jmorell@ucdavis.edu

4. **Project Keywords:**

   Nonnative Invasive Species
   Wetlands Ecology
   Wetlands, Tidal

5. **Type of project:**

   Research

6. **Does the project involve land acquisition, either in fee or through a conservation easement?**

   No

7. **Topic Area**:

   Non-Native Invasive Species

8. **Type of applicant:**

   University

9. **Location - GIS coordinates:**

Latitude: 38.118

Longitude: 122.174

Datum:

Describe project location using information such as water bodies, river miles, road intersections, landmarks, and size in acres.

Tidal marsh habitat from Petaluma Marsh in western San Pablo Bay area eastward to Decker Island in the lower Sacramento-San Joaquin Delta.

10. **Location - Ecozone:**

    1.4 Central and West Delta, 2.1 Suisun Bay & Marsh, 2.2 Napa River, 2.4 Petaluma River, Code 15: Landscape

11. **Location - County:**

    Napa, Solano, Sonoma

12. **Location - City:**

    Does your project fall within a city jurisdiction?

    No

13. **Location - Tribal Lands:**

    Does your project fall on or adjacent to tribal lands?

    No

14. **Location - Congressional District:**

    7th

15. **Location:**

    California State Senate District Number: 4th

    California Assembly District Number: 8th

16. **How many years of funding are you requesting?**

    3

17. **Requested Funds:**
    a) Are your overhead rates different depending on whether funds are state or federal?

       Yes

If yes, list the different overhead rates and total requested funds:

State Overhead Rate:	10%
Total State Funds:	113793.78
Federal Overhead Rate:	48.5%
Total Federal Funds:	152271.60

b) Do you have cost share partners <u>already identified</u>?

No

c) Do you have <u>potential</u> cost share partners?

No

d) Are you specifically seeking non-federal cost share funds through this solicitation?

No

If the total non-federal cost share funds requested above does not match the total state funds requested in 17a, please explain the difference:

18. **Is this proposal for next-phase funding of an ongoing project funded by CALFED?**

No

Have you previously received funding from CALFED for other projects not listed above?

Yes

If yes, identify project number(s), title(s) and CALFED program.

not assigned	**splittail simulation model**	**Lead Scientist's Funds**

19. **Is this proposal for next-phase funding of an ongoing project funded by CVPIA?**

No

Have you previously received funding from CVPIA for other projects not listed above?

No

20. **Is this proposal for next-phase funding of an ongoing project funded by an entity other than CALFED or CVPIA?**

Yes

If yes, identify project number(s), title(s) and funding source.

R/CZ-154 Tidal Marsh Ecology California Sea Grant

Please list suggested reviewers for your proposal. (optional)

21. **Comments:**

budget total is based on 100% state funds with 10% overhead

Environmental Compliance Checklist

<u>Invasion dynamics of perennial pepperweed, Lepidium latifolium, and their consequences for protection of natural and restored wetlands in the San Francisco Estuary</u>

1. **CEQA or NEPA Compliance**
   a) Will this project require compliance with CEQA?

      No

   b) Will this project require compliance with NEPA?

      No

   c) If neither CEQA or NEPA compliance is required, please explain why compliance is not required for the actions in this proposal.

      Project is experimental research to be done in a laboratory setting., except for final testing phase, which will be part of other projects under whose clearance we should be included.

2. **If the project will require CEQA and/or NEPA compliance, identify the lead agency(ies).** *If not applicable, put "None".*

   <u>CEQA Lead Agency:</u>
   <u>NEPA Lead Agency (or co-lead:)</u>
   <u>NEPA Co-Lead Agency (if applicable):</u>

3. **Please check which type of CEQA/NEPA documentation is anticipated.**

   CEQA
   -Categorical Exemption
   -Negative Declaration or Mitigated Negative Declaration
   -EIR
   Xnone

   NEPA
   -Categorical Exclusion
   -Environmental Assessment/FONSI
   -EIS
   Xnone

   If you anticipate relying on either the Categorical Exemption or Categorical Exclusion for this project, please specifically identify the exemption and/or exclusion that you believe covers this project.

4. **CEQA/NEPA Process**
   a) Is the CEQA/NEPA process complete?

      Not Applicable

b) If the CEQA/NEPA document has been completed, please list document name(s):

5. **Environmental Permitting and Approvals** (*If a permit is not required, leave both Required? and Obtained? check boxes blank.*)

LOCAL PERMITS AND APPROVALS

Conditional use permit

Variance

Subdivision Map Act

Grading Permit

General Plan Amendment

Specific Plan Approval

Rezone

Williamson Act Contract Cancellation

Other

STATE PERMITS AND APPROVALS

Scientific Collecting Permit Required, Obtained

CESA Compliance: 2081

CESA Compliance: NCCP

1601/03

CWA 401 certification

Coastal Development Permit

Reclamation Board Approval

Notification of DPC or BCDC

Other

FEDERAL PERMITS AND APPROVALS

ESA Compliance Section 7 Consultation

ESA Compliance Section 10 Permit Required

Rivers and Harbors Act

CWA 404

Other

PERMISSION TO ACCESS PROPERTY

Permission to access city, county or other local agency land. Agency Name:	
Permission to access state land. Agency Name: Cal Fish and Game	Required, Obtained
Permission to access federal land. Agency Name:	
Permission to access private land. Landowner Name: Solano Land Trust	Required, Obtained

6. **Comments.**

Land Use Checklist

Invasion dynamics of perennial pepperweed, Lepidium latifolium, and their consequences for protection of natural and restored wetlands in the San Francisco Estuary

1. **Does the project involve land acquisition, either in fee or through a conservation easement?**

   No

2. **Will the applicant require access across public or private property that the applicant does not own to accomplish the activities in the proposal?**

   Yes

3. **Do the actions in the proposal involve physical changes in the land use?**

   No

   If you answered no to #3, explain what type of actions are involved in the proposal (i.e., research only, planning only).

   research only. There is a possibler exception in field verification, if physical grading is required. The lead agency will acquire the necessary permits.

4. **Comments.**

Conflict of Interest Checklist

<u>Invasion dynamics of perennial pepperweed, Lepidium latifolium, and their consequences for protection of natural and restored wetlands in the San Francisco Estuary</u>

Please list below the full names and organizations of all individuals in the following categories:

- Applicants listed in the proposal who wrote the proposal, will be performing the tasks listed in the proposal or who will benefit financially if the proposal is funded.
- Subcontractors listed in the proposal who will perform some tasks listed in the proposal and will benefit financially if the proposal is funded.
- Individuals not listed in the proposal who helped with proposal development, for example by reviewing drafts, or by providing critical suggestions or ideas contained within the proposal.

The information provided on this form will be used to select appropriate and unbiased reviewers for your proposal.

Applicant(s):

Theodore Foin, University of California, Davis

Subcontractor(s):

Are specific subcontractors identified in this proposal? No

Helped with proposal development:

Are there persons who helped with proposal development?

No

Comments:

Budget Summary

Invasion dynamics of perennial pepperweed, Lepidium latifolium, and their consequences for protection of natural and restored wetlands in the San Francisco Estuary

Please provide a detailed budget for each year of requested funds, indicating on the form whether the indirect costs are based on the Federal overhead rate, State overhead rate, or are independent of fund source.

State Funds

Year 1												
Task No.	**Task Description**	**Direct Labor Hours**	**Salary *(per year)***	**Benefits *(per year)***	**Travel**	**Supplies & Expendables**	**Services or Consultants**	**Equipment**	**Other Direct Costs**	**Total Direct Costs**	**Indirect Costs**	**Total Cost**
1	CCA		10007.25	300.22	3450	3000			6000	22757.47	3617.78	26375.25
1	CCA	300	2100	63						2163.0		2163.00
2	seed expt		8187.3	245.62		2000				10432.92		10432.92
2	seed expt	80	824							824.0		824.00
		380	21118.55	608.84	3450.00	5000.00	0.00	0.00	6000.00	36177.39	3617.78	39795.17

Year 2												
Task No.	**Task Description**	**Direct Labor Hours**	**Salary *(per year)***	**Benefits *(per year)***	**Travel**	**Supplies & Expendables**	**Services or Consultants**	**Equipment**	**Other Direct Costs**	**Total Direct Costs**	**Indirect Costs**	**Total Cost**
2	growth expt		19104.75	573.14	2000	1500			5072.55	28250.44		28250.44
2	growth expt	200	1470	44.1						1514.1		1514.10
2	growth expt	160	1730.4							1730.4	3149.49	4879.89
		360	22305.15	617.24	2000.00	1500.00	0.00	0.00	5072.55	31494.94	3149.49	34644.43

Year 3												
Task No.	**Task Description**	**Direct Labor Hours**	**Salary *(per year)***	**Benefits *(per year)***	**Travel**	**Supplies & Expendables**	**Services or Consultants**	**Equipment**	**Other Direct Costs**	**Total Direct Costs**	**Indirect Costs**	**Total Cost**
3	mesocosm exp		20014.5	600.44	2000	1500			5314.1	29429.04	3486.74	32915.78
3	mesocosm exp	200	1540	46.2						1586.2		1586.20
3	mesocosm exp	200	2266							2266.0		2266.00
3	field test	200	1540	46.2						1586.2		1586.20
		600	25360.50	692.84	2000.00	1500.00	0.00	0.00	5314.10	34867.44	3486.74	38354.18

Grand Total=112793.78

Comments.

Budget Justification

Invasion dynamics of perennial pepperweed, Lepidium latifolium, and their consequences for protection of natural and restored wetlands in the San Francisco Estuary

Direct Labor Hours. Provide estimated hours proposed for each individual.

The Research Assistant associated with this proposal has her annual salary (at UC scale) listed without regard to hours, except that tasks 1 and 2 in yr 1 are split. The salary is calculated at 9 months (academic year) @ 50% time and 3 months @ 100% time. Undergraduate assistants have been calculated as two persons. The hours listed can be divided by 2 to get the individual total. Similarly, casual labor is based on two persons and can be divided in the same way.

Salary. Provide estimated rate of compensation proposed for each individual.

Research Assistants are $1213 per month @50% and 2426/month full time. Student Assistants are 7.00 per hr. Casual Labor is $10.30 per hour. 5% COLA has been included for each year.

Benefits. Provide the overall benefit rate applicable to each category of employee proposed in the project.

The benefit rate for students is 3%. Casual labor has no benefits associated with the salary. The Research Assistant is due university fee remission for each quarter enrolled. This is provided for in the other direct cost category.

Travel. Provide purpose and estimate costs for all non-local travel.

Most of the travel is for local travel, either through vehicle reimbursement or rental of a university vehicle. One conference meeting per year is included, assuming out of state locations but not international.

Supplies & Expendables. Indicate separately the amounts proposed for office, laboratory, computing, and field supplies.

All supplies are directly associated with the proect, including equipment in the first year that does not meet the definition of 5K per item. Computing and office supplies are being paid for by faculty funds. These include new balances, pH meter, GPS locator, and an outboard motor and boat trailer.

Services or Consultants. Identify the specific tasks for which these services would be used. Estimate amount of time required and the hourly or daily rate.

not applicable

Equipment. Identify non-expendable personal property having a useful life of more than one (1) year and an acquisition cost of more than $5,000 per unit. If fabrication of equipment is proposed, list parts and materials required for each, and show costs separately from the other items.

not applicable

Project Management. Describe the specific costs associated with insuring accomplishment of a specific project, such as inspection of work in progress, validation of costs, report preparation, giving presentatons, reponse to project specific questions and necessary costs directly associated with specific project oversight.

Publication and conference costs are the only ones included in this budget. All administrative costs are included in overhead.

Other Direct Costs. Provide any other direct costs not already covered.

Each year includes the fee remission with an anticipated 5% inflation factor. The first year includes publication costs (figures and page charges, reprints).

Indirect Costs. Explain what is encompassed in the overhead rate (indirect costs). Overhead should include costs associated with general office requirements such as rent, phones, furniture, general office staff, etc., generally distributed by a predetermined percentage (or surcharge) of specific costs.

Overhead is 10% of total direct costs by negotiation with the State of California and CALFED.

Executive Summary

<u>Invasion dynamics of perennial pepperweed, Lepidium latifolium, and their consequences for protection of natural and restored wetlands in the San Francisco Estuary</u>

The relatively recent introductions of two highly successful exotics, Spartina alterniflora and Lepidium latifolium, threaten the structure and functional integrity of those remaining Bay-Delta wetlands and may have a devastating impact on marsh restoration. While Spartina alterniflora is the subject of continuing research, comparatively little is known about Lepidium latifolium in light of its potential impact on the Bay-Delta system. L. latifolium has been shown to invade riparian corridors, freshwater, brackish, and saline tidal wetlands successfully. The objective of this proposal is to determine the characteristics of Lepidium latifolium that facilitate its colonization and of the tidal marshes it invades. This research is expected to reveal demographic weaknesses, which when translated into restoration policy, would help check the establishment of Lepidium, enhancing the protection of natural wetlands and preventing its invasion into restored wetlands. The proposed research focuses on the determination of life history and population biology; the combination of reproductive life history strategies and environmental characteristics associated with L. latifolium invasibility; and testing the emerging model of L. latifolium - environment interactions on simulated tidal marshes, with field verification in San Francisco Bay and Suisun Bay sites. The proposed research should enhance the development of a control strategy for one of the areas most noxious wetland weeds. Eradication of this species is extremely difficult or impossible once it is well-established; our expected control strategy will focus on prevention of spread, reduction of threat to restored areas, and mitigation of negative impacts. In addition, this research will provide improved mechanistic understanding of how L. latifolium successfully invades tidal marshes, the environmental determinants of its success and most effective control strategies. By so doing, it will address one of the most serious problems identified in the CALFED Ecosystem Restoration Plan. The research protocol could serve as a model for other exotic wetland plant invaders and so its benefits may reach beyond Lepidium itself..

Proposal

University of California, Davis

Invasion dynamics of perennial pepperweed, Lepidium latifolium, and their consequences for protection of natural and restored wetlands in the San Francisco Estuary

Theodore Foin, University of California, Davis

PROPOSAL TITLE:	**INVASION DYNAMICS OF PERENNIAL PEPPERWEED, *LEPIDIUM LATIFOLIUM*, AND THEIR CONSEQUENCES FOR PROTECTION OF NATURAL AND RESTORED WETLANDS IN THE SAN FRANCISCO ESTUARY**
Principal Investigator:	Theodore C. Foin University of California, Davis
Proposal Starting Date:	1 January 2002
Period of Support:	3 years
Budget Requested:	$113793.78

THE PROBLEM: MINIMIZING INVASIVE SPECIES IN RESTORING TIDAL MARSHES IN THE SAN FRANCISCO ESTUARY

Successful wetlands restoration is one of the core goals of the CALFED program. Although many specific restoration programs have been proposed and funded, the need for scientifically rigorous experiments with repeatable results and adaptive responses built-in remains a major concern of the agency. One of the most serious problems affecting restoration success is the distinct possibility that a restored marsh might be dominated by an undesirable invasive species, an outcome that might be worse than the degraded marsh it was intended to replace. Some marsh biologists have even expressed concern that marsh restoration should not proceed without an effective program to prevent invasion by aggressive exotics (D. R. Ayres, personal communication).

The threat of invasive plants to the tidal marshes of the lower Delta and San Pablo Bay regions of the San Francisco Estuary is most certain for two species. One is smooth cordgrass (*Spartina alterniflora*), a serious problem in fully tidal salt marshes of San Francisco Bay. Don Strong and colleagues are currently working on the former, mostly in San Francisco Bay but also in Washington. The other species is perennial pepperweed, *Lepidium latifolium*, a tall forb which occurs throughout the Estuary, in alkali sinks, in cool deserts and even annual and perennial grasslands, through which it spreads with ease (Mark Renz, unpublished research).

Lepidium latifolium has received much less attention but it may actually be the more dangerous of the two species. It has vital attributes and a life history that are characteristic of prototypic exotics (Rejmanek, 1996). It is a member of the mustard family (Cruciferae), a family known for having many weedy species, numerous small and easily dispersed seed, and ability to reach large sizes. *Lepidium latifolium* shares these family traits; in addition, it is large (reaching 1 m or more in height) and highly fertile (freely produces lateral branches, each with numerous flowers and small, easily dispersed seed). *L. latifolium* grows fast and has a large, aggressive root system, which enables it to compete effectively with other perennials while retaining the reproductive effort of

annuals, It reproduces by both sexual and vegetative means (Trumbo, 1994). Furthermore, *L. latifolium* may compete with other species by pumping salt ions from deep in the soil profile to the surface, making the immediate surroundings less suitable for other species (Blank and Young, 1997).

One known weakness in the biology of *L. latifolium* is that it is not effective in colonizing the upper marsh. It has some ability to tolerate or survive saturated conditions and the elevated soil salinities found there, but is not known to grow well under these conditions (Chen et al, 2001; May, 1995; Young and Turner, 1995). Consequently, *Lepidium latifolium* poses its gravest threat to the streamside zone, which generally has moderated salinity, abundant water, and better drainage. Despite its relatively recent introduction into Pacific tidal marshes, *L. latifolium* has spread quickly along stream courses, and is considered a serious invader of this zone from full salt marshes upriver to muted tidal and freshwater marshes. In our opinion, its aggressive growth, euryhaline tolerance, persistence in face of attempts to eradicate it and its potential for altering the functional role of estuarine vegetation through competitive displacement make it a very serious threat to marsh restoration programs.

PROPOSAL JUSTIFICATION

Although we naturally focus on invasive species with greater economic or ecological impact, there is little conceptual distinction between biological invaders and recolonization by native species. Colonization by any species is the joint product of site invasibility and those vital attributes of the potential colonist that facilitate its dispersal and colonization. This proposal is organized around this basic principle, focusing upon the relative impact of each component of colonist demography and physiological requirements and environmental resistance.

Prior research with *L. latifolium* suggests 1) that seed dispersal is not limiting; 2) that once plants produce large rhizomes, they cannot be easily displaced; and 3) the critical demographic phase is in establishment and maturation in the first year. Maturation is particularly important since these plants subsequently become local seed sources. Since experience shows that adequate control after establishment is at best difficult and environmentally disruptive, colonization of restoration sites by *Lepidium* must be prevented by some combination of increased site resistance and exploitation of demographic bottlenecks. We seek to estimate the risk of *Lepidium* establishment by measuring site invasibility and defining its colonization strategies from its biological and ecological traits. We can then combine both types of information to test the invasion success by *L. latifolium* in simulated marsh stands and environmental conditions. The goal of this research is to minimize the spread of pepperweed by elucidating the conditions under which it is favored and by potentially providing the opportunity to exploit weaknesses in the life history and population biology of *L. latifolium* to control its spread throughout Estuary marshes.

Adaptive management is expected to be of less concern with this proposal than with restoration programs. Because the research is with a dangerous exotic, most of it will be in the laboratory under controlled conditions. Experiments that do not turn out as

expected are a problem of ordinary science; the adjustments are technically part of adaptive management, but the potential negative consequences are much smaller. The final field tests can fail, and lead to growth and establishment of *Lepidium* despite the design and expectations. The appropriate response under these conditions will be to destroy the *Lepidium* at the end of the first year.

OBJECTIVES OF THIS PROPOSAL

This proposal has three specific objectives.

1. To determine the properties of tidal marshes governing their invasibility by exotic species, with special regard to different positions in the wetland landscape.

2. To determine the combination of reproductive life history strategies and environmental characteristics that are associated with *Lepidium latifolium* invasibility.

3. To test the emerging model of ecological influences on colonization by *Lepidium latifolium* on simulated tidal marshes.

The outcome of this project should be a much-improved picture of the requirements and responses of *Lepidium latifolium* in marsh environments, and possibly a strategy for minimizing its dispersal. As such, this research will provide the biological foundation upon which a control strategy can be built.

PROPOSED APPROACH

Objective 1. To determine the properties of tidal marshes governing their invasibility by exotic species, particularly Lepidium latifolium.

It is important to discover which attributes of tidal marshes in the San Francisco Estuary are key determinants of successful pepperweed colonization. Our previous research has shown that *L. latifolium* is largely restricted to the streamside zone in tidal marshes; often the smaller channels in the marsh are delineated by a mixture of *fringing Scirpus* spp. and *Lepidium*. Our mathematical model (developed from the conceptual model in Foin *et al.* 2000) suggests that a combination of more abundant water supply and regular flushing of salinity acts to open these sites to *Lepidium* colonization. Conversely, the upper marsh may have persistent high water levels with too highly elevated soil salinity to support *Lepidium* invasion. Thus, the principal focus of this phase of the research will be the streamside zone.

In order to elucidate environmental factors contributing to *Lepidium latifolium* invasion, canonical correspondence analysis (hereafter abbreviated to CCA) will be used to regress streamside species and sampling units against environmental factors. CCA

allows the user to compare species and distribution patterns and environmental variables in a single step by combining regression with multivariate analysis. The sampling units will consist of 1 m^2 units. The analysis will be run using *Lepidium* as an environmental factor in order to examine species correlations, and then with pepperweed grouped with the other species to affirm that salinity is the dominant gradient responsible for segregating species and to suggest other factors which may be significant determinants. Data will be collected at multiple sites along a salinity gradient ranging from full strength seawater (western San Pablo Bay sites) to fresh water (Suisun Marsh). The exact sites to be sampled will include Rush Ranch and Petaluma Marsh, plus a series of younger marshes to be chosen from sites along San Pablo Bay and others in the Suisun Marsh in Solano County. A minimum of 20-1 m^2 samples will be collected from each site. Species composition, percent cover, and several environmental variables (channel salinity, soil salinity, flooding regime interpolated from tide tables, pH, soil particle size, and percent organic matter) will be recorded for each sample. Sampling will be conducted in one short time period at each site, but can be repeated in subsequent years if the analysis requires it.

The results will be analyzed using PC-Ord (McCune, 1999) for CCA. We expect the results to confirm the hypothesis that increasing salinity is the dominant environmental factor limiting successful pepperweed invasion. This hypothesis was developed from a 2001 experiment measuring growth under different salinity and flooding conditions under controlled conditions. We next need to confirm these results in the field, with natural conditions of tidal input and soil. It will be particularly important to examine the influence of these covariates as clues to the mechanisms limiting *Lepidium*.

Objective 2. To determine the combination of reproductive life history strategies and environmental characteristics that are associated with Lepidium latifolium invasibility.

Two principal means for pepperweed dispersal (rhizome fragmentation and seed dispersal) have been documented. Field observations have shown that broken rhizomes are an important source of propagules for dispersing pepperweed (M. Renz, pers. comm.). This is a difficult mechanism to study, given the erratic dispersal of broken rhizomes and the numerous conditions that can influence their growth. The difficulty in making satisfactory experimental measurements of rhizome establishment rates is a daunting problem. We concede that rhizomes are probably important propagules, especially after a reproducing population has established either locally or at some location upstream of the site. Our best evidence of significant colonization by rhizomes may be indirect, resulting from seeing successful establishment in the field that cannot be accounted for by seedling germination and growth.

The rapid establishment of *Lepidium* across the western states suggests that seed dispersal is probably the principal means of expansion. *L. latifolium* routinely produces numerous seed, but to date the role of seed in colonization has not been quantified. The copious seed suggests that wind and animal dispersal are important mechanisms for

pepperweed colonization, at least in streamside habitats, and perhaps the most important one.

Seed dispersal and early growth. Because seed are both numerous and readily dispersed, it seems safe to assume that dispersal is not a major limiting factor on *Lepidium* invasibility, and instead concentrate upon establishment.

Experimental seeding in the field has obvious flaws and dangers, so laboratory experiments will be the principal means for assessing the reproductive strategies of *Lepidium latifolium*. This research will examine the success of reproduction from seed in relation to the nature of the stand. We propose to seed pepperweed into stands of native streamside dominants of varying densities, from bare ground to normal densities under different salinities (0, 15, 35 ppt - the range of salinities found in the streamside zone in the Estuary) in the laboratory for better control over site conditions. *L. latifolium* will be seeded into stands of native dominants (*S. acutus, S. americanus. S. maritimus*) to determine the importance of seedling survivorship to *L. latifolium* expansion. This will be a randomized complete block design with salinity assigned to the main plots and *Scirpus* cover randomly assigned within blocks. The number (estimated by weight of seed sown) of *L. latifolium* seeds will be constant across treatments. The response variable will be the estimated number of germinated seeds and number surviving to seedlings and adulthood, broken down into size groups (height <5cm, 5-30 cm, 30-60 cm, and >60 cm). There will be 8 replicates per treatment. Results will be analyzed with ANOVA and quantified by regression equations. We hypothesize that these competitive relationships, in the context of prevailing salinity conditions, will determine the rate of *Lepidium* growth and its long-term establishment.

Post-colonization growth and establishment. *Lepidium latifolium* can be expected to compete against the tules (*Scirpus* spp.) normally found in the streamside zone. The previous experiment should tell us how much tule stands can be expected to resist *Lepidium* invasion. The effect of *Lepidium* on *Scirpus* spp. is the subject of the next experiment. To assess the potential for competitive displacement of tules in tidal marshes, growth responses of *Lepidium latifolium* will be compared to three native wetland streamside dominants (the same three *Scirpus* as in the seeding experiment)across a range of salinity treatments. The experiment monitors the growth of each of the three species in growth boxes under three salinity treatments (0, 15, 35 ppt) and two flooding regimes (daily, every 4th day). The experimental design is a split plot design with salinity as the main plot, flooding regime the subplot, and species identity randomly assigned to the subplots. Plants will be propagated from root stock. There will be four replicates per treatment, and four subsamples in each sampling unit to reduce variability of root stock. The number of replicates is constrained by the number of treatments and plumbing constraints. Preliminary results from a pilot experiment done this year indicate that this is an adequate number of replicates for the variance expected. Above- and below-ground biomass will be collected at the end of the growing season. Growth response will also be monitored throughout the growing season by repeatedly measuring the growth of randomly selected stems in each experimental unit Results will be analyzed with repeated measures ANOVA.

Objective 3. To test the emerging model of ecological influences on colonization by Lepidium latifolium on simulated tidal marshes.

The results from earlier experiments will allow us to identify those species and environmental variables having the greatest effect on *Lepidium* invasion success. These results will permit us to establish stand conditions that should vary with respect to suitability for *Lepidium* seedlings. Such stands will be planted as a validation experiment, set up in mesocosms that will have simulated tidal and salinity conditions to match the combinations having the greatest effect on invasibility. The design will be a randomized complete block design with five replicates. The treatments will be selected from the series of conditions elucidated above that are most applicable to pepperweed invasion. Satisfactory rank order in invasion success will serve to test our understanding.

Successful validation will open the possibility for field tests of planting strategies that can be tested in sites being restored in the field. Although this aspect remains too preliminary to promise as a finite objective, such field experiments will be discussed in our interactions with the Simenstad-Reed-Phil Williams team and the DWR marsh restoration program, both of which will be conducting restoration programs and who have indicated their willingness to collaborate with us. Since we will not deliberately introduce *Lepidium* seed into the field, we will require sites at which pepperweed is already present in the general area. Field validation is one way to address any lingering concerns about our ability to produce satisfactory mescosms (see Callaway *et al.*1997). Whether or not field validation can be performed, we expect this proposal to identify species, planting schemes and environmental conditions which have the greatest exclusionary impact on pepperweed.

FEASIBILITY

This proposal is based on methods that have been well tested in ecology, marsh biology and the field in previous research leading up to this one. The laboratory-based and field survey elements of this proposal are demonstrably feasible and no insurmountable problems are expected to arise therein.

The final field-based tests of *Lepidium* exclusion will require permits. We hope to be included in existing or forthcoming permits at Simenstad-Reed Williams and/or DWR sites. The exact design elements cannot be specified until the laboratory results are in and analyzed, but hopefully will result in feasible restoration schemes (planting densities, species type, and predominant hydrologic-geomorphic conditions).

PERFORMANCE MEASURES

The only aspect of this proposal subject to specification of a successful performance evaluation will be the field experiment. Once the treatments are in place, the experiment will have to be routinely monitored for *Lepidium* colonization, most likely over a two-year period to allow for two germination and growth cycles. *Lepidium*

seedlings appearing in the site are not sufficient to judge the experiment a failure; *Lepidium* must grow and produce seed to meet this condition. If *Lepidium* seed are locally available but there is no successful colonization within the two years, the experiment will be deemed successful.

DATA HANDLING AND STORAGE

All data will be stored in a data vault system maintained and backed up in the Computing Facility of the Department of Agronomy and Range Science, University of California, Davis. Results will be posted to our website at agronomy.ucdavis.edu.

OUTCOMES AND EXPECTED BENEFITS OF THIS RESEARCH

If the research progresses as outlined, we think a testable *Lepidium* prevention strategy will emerge before the end of the project term. By elucidating the conditions under which pepperweed is favored and by potentially providing the opportunity to exploit vulnerabilities in its life history and population biology to control its spread, we should be able to develop an improved picture of the requirements and responses of *Lepidium latifolium* in marsh environments, and possibly a strategy for minimizing its dispersal. This can be further tested in the field or implemented without increasing the risk of *Lepidium* invasion.
We shall participate in future CALFED science conferences, publish in regular journals, and perhaps produce a manual on planting and environmental management that minimizes the risk of *Lepidium* invasion.

WORK SCHEDULE

Objective	Task	Timeframe
1	field survey using CCA	June-September 2002
2	experimental seeding into *Scirpus* spp.	May-October 2002
2	growth in competition with *Scirpus* spp.	May-October 2003
3	mesocosm tests in simulated streamside stands	February-September 2004
3	field verification	February 2005-October 2006

The off-season (November-February) is reserved for data analysis. Above-ground material will be collected from Rush Ranch to support a regression of plant height against biomass for each species. In the fall of 2001, native streamside dominants will be placed into growth chambers to grow them out for the stands of the seeding

experiment beginning in the spring, 2002. We will collect data on species and environmental factors for the CCA in the summer of 2002. In the spring of 2004, the mesocosm experiments will begin and will continue through the fall. Technically, field verification proceeds beyond the term of this proposal, although planting of experimental stands will likely be completed in 2004. Details of monitoring will continue, but exact arrangements will have to be made later.

Applicability to ERP Goals

The four ERP goals applicable to this proposal are:

Goal 1: *protection and restoration of native biotic communities*

Goal 2: *Rehabilitate natural aquatic and adjacent plant communities to support native members of those areas*

Goal 4: *Protect and/or restore functional habitat types in the Bay-Delta estuary and its watershed for ecological and public values such as supporting species and biotic communities, ecological processes, recreation, scientific research, and aesthetics, including restoration of tidal marsh, sloughs, seasonal and riparian wetlands and protecting tracts of existing high quality wetland*

Goal 5: *Prevent establishment of additional non-native invasive species and reduce the negative ecological and economic impacts of established non-natives in the Bay-Delta estuary and its watershed, including where possible limiting spread or eradication of non-natives*

The proposed research will directly address each of these four goals. *Lepidium latifolium* is specifically identified as a major problem in the Bay-Delta estuary and its watershed. This species poses a grave threat to remaining wetlands in the Bay-Delta system and to proposed restoration projects because it is highly successful across a wide spectrum of wetland habitats. This research seeks to provide a mechanistic understanding of the way in which *L. latifolium* is able to invade a wetland site with respect to the invader and the environmental characteristics of the site. Development of a successful control protocol would help protect remaining intact systems; provide a means for reducing its spread; and prevent the invasion of *Lepidium latifolium* into restoring sites.

PREVIOUS CALFED SUPPORT

I have support from the Science Advisors funds (30K) to support mathematical modeling population dynamics of splittail. *Pogonicthys macrolepidopterus*. This work is completely separate from this proposal.

SYSTEM-WIDE ECOSYSTEM BENEFITS

This proposal seeks to develop and test the adequacy of a protocol to address the invasibility of tidal marshes, and secondarily to find management schemes which

maximize exclusion of pepperweed. To the extent to which this proposal is productive, we can expect to improve restoration by excluding *Lepidium*, and perhaps develop a protocol that can be used for a larger number of invasive plant species.

QUALIFICATIONS

ABBREVIATED CURRICULUM VITAE
THEODORE C. FOIN
Updated 9 October 2000

EDUCATIONAL SUMMARY

A.B., Biological Sciences, Stanford University, 1962
Ph.D., Zoology (Ecology), University of North Carolina, Chapel Hill, 1967

CURRENT ACADEMIC POSITION

Professor
Department of Agronomy and Range Science
University of California, Davis 95616
1998-Present

ROUTINE TEACHING RESPONSIBILITIES

ASE 121. Systems Analysis in Agriculture and Resource Management
Ecology 200B. Principles and Application of Ecological Theory.
Ecology 201. Modeling Ecosystems and Landscapes

GRADUATE EDUCATION

Member of the Graduate Groups in Ecology, International Agricultural Development, Horticulture and Plant Biology.
18 MS and 11 PhD students have finished under my direction over the course of my career; 3 PhD and 2 MS are in progress.

RECENT PROFESSIONAL AND PUBLIC SERVICE

Editorial Board, *Population and Environment*
Yolo County Grand Jury, 1991-92
Member of the following professional societies: American Institute of Biological Sciences, California Botanical Society, Ecological Society of America, International Society of Ecological Modelers, Sigma Xi
Chair of Committee of Science Advisors and member of the Board of Directors, San Francisco Estuary Institute.
Member of Science Review Committee, Regional Wetlands Goals Project, San Francisco Estuary Institute.

RESEARCH INTERESTS

My principal activities fall in the following areas:

* The theory and practice of ecological modeling.
* Management-oriented simulation of rice-weed interactions, with special respect to competition for light. Projects in this area are in progress in California and tropical Asia.
* Ecology and simulation of tidal salt marshes and their inhabitants. Current work is focussed on California clapper rails in the San Francisco Estuary, and their relative dependence upon stream evolution and the vegetation.
* Tidal marsh landscape dynamics of the San Francisco Estuary.

RECENT PUBLICATIONS

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Caton, B. P., K. D. Gibson, T. C. Foin, and J. E. Hill, 2001. Evaluating the potential contribution of simulation models to the identification of competitive crop traits. *Field Crops Research*.

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Invasion dynamics of perennial pepperweed, Lepidium latifolium, and their consequences for protection of natural and restored wetlands in the San Francisco Estuary

Project Information

1. **Proposal Title:**

   Invasion dynamics of perennial pepperweed, Lepidium latifolium, and their consequences for protection of natural and restored wetlands in the San Francisco Estuary

2. **Proposal applicants:**

   Theodore Foin, University of California, Davis

3. **Corresponding Contact Person:**

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   Director of Sponsored Programs Office of Research, 118 Everson Hall UC Davis 1 Shields Avenue Davis CA 95616-8671
   530 752-6933
   jmorell@ucdavis.edu

4. **Project Keywords:**

   Nonnative Invasive Species
   Wetlands Ecology
   Wetlands, Tidal

5. **Type of project:**

   Research

6. **Does the project involve land acquisition, either in fee or through a conservation easement?**

   No

7. **Topic Area**:

   Non-Native Invasive Species

8. **Type of applicant:**

   University

9. **Location - GIS coordinates:**

Latitude: 38.118

Longitude: 122.174

Datum:

Describe project location using information such as water bodies, river miles, road intersections, landmarks, and size in acres.

Tidal marsh habitat from Petaluma Marsh in western San Pablo Bay area eastward to Decker Island in the lower Sacramento-San Joaquin Delta.

10. **Location - Ecozone:**

    1.4 Central and West Delta, 2.1 Suisun Bay & Marsh, 2.2 Napa River, 2.4 Petaluma River, Code 15: Landscape

11. **Location - County:**

    Napa, Solano, Sonoma

12. **Location - City:**

    Does your project fall within a city jurisdiction?

    No

13. **Location - Tribal Lands:**

    Does your project fall on or adjacent to tribal lands?

    No

14. **Location - Congressional District:**

    7th

15. **Location:**

    California State Senate District Number: 4th

    California Assembly District Number: 8th

16. **How many years of funding are you requesting?**

    3

17. **Requested Funds:**
    a) Are your overhead rates different depending on whether funds are state or federal?

       Yes

If yes, list the different overhead rates and total requested funds:

State Overhead Rate:	10%
Total State Funds:	113793.78
Federal Overhead Rate:	48.5%
Total Federal Funds:	152271.60

b) Do you have cost share partners already identified?

No

c) Do you have potential cost share partners?

No

d) Are you specifically seeking non-federal cost share funds through this solicitation?

No

If the total non-federal cost share funds requested above does not match the total state funds requested in 17a, please explain the difference:

18. **Is this proposal for next-phase funding of an ongoing project funded by CALFED?**

No

Have you previously received funding from CALFED for other projects not listed above?

Yes

If yes, identify project number(s), title(s) and CALFED program.

not assigned	**splittail simulation model**	**Lead Scientist's Funds**

19. **Is this proposal for next-phase funding of an ongoing project funded by CVPIA?**

No

Have you previously received funding from CVPIA for other projects not listed above?

No

20. **Is this proposal for next-phase funding of an ongoing project funded by an entity other than CALFED or CVPIA?**

Yes

If yes, identify project number(s), title(s) and funding source.

R/CZ-154 Tidal Marsh Ecology California Sea Grant

Please list suggested reviewers for your proposal. (optional)

21. **Comments:**

budget total is based on 100% state funds with 10% overhead

Environmental Compliance Checklist

<u>Invasion dynamics of perennial pepperweed, Lepidium latifolium, and their consequences for protection of natural and restored wetlands in the San Francisco Estuary</u>

1. **CEQA or NEPA Compliance**
   a) Will this project require compliance with CEQA?

      No

   b) Will this project require compliance with NEPA?

      No

   c) If neither CEQA or NEPA compliance is required, please explain why compliance is not required for the actions in this proposal.

      Project is experimental research to be done in a laboratory setting., except for final testing phase, which will be part of other projects under whose clearance we should be included.

2. **If the project will require CEQA and/or NEPA compliance, identify the lead agency(ies).** *If not applicable, put "None".*

   <u>CEQA Lead Agency:</u>
   <u>NEPA Lead Agency (or co-lead:)</u>
   <u>NEPA Co-Lead Agency (if applicable):</u>

3. **Please check which type of CEQA/NEPA documentation is anticipated.**

   CEQA
   -Categorical Exemption
   -Negative Declaration or Mitigated Negative Declaration
   -EIR
   Xnone

   NEPA
   -Categorical Exclusion
   -Environmental Assessment/FONSI
   -EIS
   Xnone

   If you anticipate relying on either the Categorical Exemption or Categorical Exclusion for this project, please specifically identify the exemption and/or exclusion that you believe covers this project.

4. **CEQA/NEPA Process**
   a) Is the CEQA/NEPA process complete?

      Not Applicable

b) If the CEQA/NEPA document has been completed, please list document name(s):

5. **Environmental Permitting and Approvals** (*If a permit is not required, leave both Required? and Obtained? check boxes blank.*)

LOCAL PERMITS AND APPROVALS

Conditional use permit

Variance

Subdivision Map Act

Grading Permit

General Plan Amendment

Specific Plan Approval

Rezone

Williamson Act Contract Cancellation

Other

STATE PERMITS AND APPROVALS

Scientific Collecting Permit Required, Obtained

CESA Compliance: 2081

CESA Compliance: NCCP

1601/03

CWA 401 certification

Coastal Development Permit

Reclamation Board Approval

Notification of DPC or BCDC

Other

FEDERAL PERMITS AND APPROVALS

ESA Compliance Section 7 Consultation

ESA Compliance Section 10 Permit Required

Rivers and Harbors Act

CWA 404

Other

PERMISSION TO ACCESS PROPERTY

Permission to access city, county or other local agency land. Agency Name:	
Permission to access state land. Agency Name: Cal Fish and Game	Required, Obtained
Permission to access federal land. Agency Name:	
Permission to access private land. Landowner Name: Solano Land Trust	Required, Obtained

6. **Comments.**

Land Use Checklist

Invasion dynamics of perennial pepperweed, Lepidium latifolium, and their consequences for protection of natural and restored wetlands in the San Francisco Estuary

1. **Does the project involve land acquisition, either in fee or through a conservation easement?**

   No

2. **Will the applicant require access across public or private property that the applicant does not own to accomplish the activities in the proposal?**

   Yes

3. **Do the actions in the proposal involve physical changes in the land use?**

   No

   If you answered no to #3, explain what type of actions are involved in the proposal (i.e., research only, planning only).

   research only. There is a possibler exception in field verification, if physical grading is required. The lead agency will acquire the necessary permits.

4. **Comments.**

Conflict of Interest Checklist

Invasion dynamics of perennial pepperweed, Lepidium latifolium, and their consequences for protection of natural and restored wetlands in the San Francisco Estuary

Please list below the full names and organizations of all individuals in the following categories:

- Applicants listed in the proposal who wrote the proposal, will be performing the tasks listed in the proposal or who will benefit financially if the proposal is funded.
- Subcontractors listed in the proposal who will perform some tasks listed in the proposal and will benefit financially if the proposal is funded.
- Individuals not listed in the proposal who helped with proposal development, for example by reviewing drafts, or by providing critical suggestions or ideas contained within the proposal.

The information provided on this form will be used to select appropriate and unbiased reviewers for your proposal.

Applicant(s):

Theodore Foin, University of California, Davis

Subcontractor(s):

Are specific subcontractors identified in this proposal? No

Helped with proposal development:

Are there persons who helped with proposal development?

No

Comments:

Budget Summary

<u>Invasion dynamics of perennial pepperweed, Lepidium latifolium, and their consequences for protection of natural and restored wetlands in the San Francisco Estuary</u>

Please provide a detailed budget for each year of requested funds, indicating on the form whether the indirect costs are based on the Federal overhead rate, State overhead rate, or are independent of fund source.

<u>State Funds</u>

Year 1												
Task No.	**Task Description**	**Direct Labor Hours**	**Salary *(per year)***	**Benefits *(per year)***	**Travel**	**Supplies & Expendables**	**Services or Consultants**	**Equipment**	**Other Direct Costs**	**Total Direct Costs**	**Indirect Costs**	**Total Cost**
1	CCA		10007.25	300.22	3450	3000			6000	22757.47	3617.78	26375.25
1	CCA	300	2100	63						2163.0		2163.00
2	seed expt		8187.3	245.62		2000				10432.92		10432.92
2	seed expt	80	824							824.0		824.00
		380	21118.55	608.84	3450.00	5000.00	0.00	0.00	6000.00	36177.39	3617.78	39795.17

Year 2												
Task No.	**Task Description**	**Direct Labor Hours**	**Salary *(per year)***	**Benefits *(per year)***	**Travel**	**Supplies & Expendables**	**Services or Consultants**	**Equipment**	**Other Direct Costs**	**Total Direct Costs**	**Indirect Costs**	**Total Cost**
2	growth expt		19104.75	573.14	2000	1500			5072.55	28250.44		28250.44
2	growth expt	200	1470	44.1						1514.1		1514.10
2	growth expt	160	1730.4							1730.4	3149.49	4879.89
		360	22305.15	617.24	2000.00	1500.00	0.00	0.00	5072.55	31494.94	3149.49	34644.43

Year 3												
Task No.	**Task Description**	**Direct Labor Hours**	**Salary *(per year)***	**Benefits *(per year)***	**Travel**	**Supplies & Expendables**	**Services or Consultants**	**Equipment**	**Other Direct Costs**	**Total Direct Costs**	**Indirect Costs**	**Total Cost**
3	mesocosm exp		20014.5	600.44	2000	1500			5314.1	29429.04	3486.74	32915.78
3	mesocosm exp	200	1540	46.2						1586.2		1586.20
3	mesocosm exp	200	2266							2266.0		2266.00
3	field test	200	1540	46.2						1586.2		1586.20
		600	25360.50	692.84	2000.00	1500.00	0.00	0.00	5314.10	34867.44	3486.74	38354.18

Grand Total=<u>112793.78</u>

Comments.

Budget Justification

Invasion dynamics of perennial pepperweed, Lepidium latifolium, and their consequences for protection of natural and restored wetlands in the San Francisco Estuary

Direct Labor Hours. Provide estimated hours proposed for each individual.

The Research Assistant associated with this proposal has her annual salary (at UC scale) listed without regard to hours, except that tasks 1 and 2 in yr 1 are split. The salary is calculated at 9 months (academic year) @ 50% time and 3 months @ 100% time. Undergraduate assistants have been calculated as two persons. The hours listed can be divided by 2 to get the individual total. Similarly, casual labor is based on two persons and can be divided in the same way.

Salary. Provide estimated rate of compensation proposed for each individual.

Research Assistants are $1213 per month @50% and 2426/month full time. Student Assistants are 7.00 per hr. Casual Labor is $10.30 per hour. 5% COLA has been included for each year.

Benefits. Provide the overall benefit rate applicable to each category of employee proposed in the project.

The benefit rate for students is 3%. Casual labor has no benefits associated with the salary. The Research Assistant is due university fee remission for each quarter enrolled. This is provided for in the other direct cost category.

Travel. Provide purpose and estimate costs for all non-local travel.

Most of the travel is for local travel, either through vehicle reimbursement or rental of a university vehicle. One conference meeting per year is included, assuming out of state locations but not international.

Supplies & Expendables. Indicate separately the amounts proposed for office, laboratory, computing, and field supplies.

All supplies are directly associated with the proect, including equipment in the first year that does not meet the definition of 5K per item. Computing and office supplies are being paid for by faculty funds. These include new balances, pH meter, GPS locator, and an outboard motor and boat trailer.

Services or Consultants. Identify the specific tasks for which these services would be used. Estimate amount of time required and the hourly or daily rate.

not applicable

Equipment. Identify non-expendable personal property having a useful life of more than one (1) year and an acquisition cost of more than $5,000 per unit. If fabrication of equipment is proposed, list parts and materials required for each, and show costs separately from the other items.

not applicable

Project Management. Describe the specific costs associated with insuring accomplishment of a specific project, such as inspection of work in progress, validation of costs, report preparation, giving presentatons, reponse to project specific questions and necessary costs directly associated with specific project oversight.

Publication and conference costs are the only ones included in this budget. All administrative costs are included in overhead.

Other Direct Costs. Provide any other direct costs not already covered.

Each year includes the fee remission with an anticipated 5% inflation factor. The first year includes publication costs (figures and page charges, reprints).

Indirect Costs. Explain what is encompassed in the overhead rate (indirect costs). Overhead should include costs associated with general office requirements such as rent, phones, furniture, general office staff, etc., generally distributed by a predetermined percentage (or surcharge) of specific costs.

Overhead is 10% of total direct costs by negotiation with the State of California and CALFED.

Executive Summary

Invasion dynamics of perennial pepperweed, Lepidium latifolium, and their consequences for protection of natural and restored wetlands in the San Francisco Estuary

The relatively recent introductions of two highly successful exotics, Spartina alterniflora and Lepidium latifolium, threaten the structure and functional integrity of those remaining Bay-Delta wetlands and may have a devastating impact on marsh restoration. While Spartina alterniflora is the subject of continuing research, comparatively little is known about Lepidium latifolium in light of its potential impact on the Bay-Delta system. L. latifolium has been shown to invade riparian corridors, freshwater, brackish, and saline tidal wetlands successfully. The objective of this proposal is to determine the characteristics of Lepidium latifolium that facilitate its colonization and of the tidal marshes it invades. This research is expected to reveal demographic weaknesses, which when translated into restoration policy, would help check the establishment of Lepidium, enhancing the protection of natural wetlands and preventing its invasion into restored wetlands. The proposed research focuses on the determination of life history and population biology; the combination of reproductive life history strategies and environmental characteristics associated with L. latifolium invasibility; and testing the emerging model of L. latifolium - environment interactions on simulated tidal marshes, with field verification in San Francisco Bay and Suisun Bay sites. The proposed research should enhance the development of a control strategy for one of the areas most noxious wetland weeds. Eradication of this species is extremely difficult or impossible once it is well-established; our expected control strategy will focus on prevention of spread, reduction of threat to restored areas, and mitigation of negative impacts. In addition, this research will provide improved mechanistic understanding of how L. latifolium successfully invades tidal marshes, the environmental determinants of its success and most effective control strategies. By so doing, it will address one of the most serious problems identified in the CALFED Ecosystem Restoration Plan. The research protocol could serve as a model for other exotic wetland plant invaders and so its benefits may reach beyond Lepidium itself..

Proposal

University of California, Davis

Invasion dynamics of perennial pepperweed, Lepidium latifolium, and their consequences for protection of natural and restored wetlands in the San Francisco Estuary

Theodore Foin, University of California, Davis

PROPOSAL TITLE: **INVASION DYNAMICS OF PERENNIAL PEPPERWEED, *LEPIDIUM LATIFOLIUM*, AND THEIR CONSEQUENCES FOR PROTECTION OF NATURAL AND RESTORED WETLANDS IN THE SAN FRANCISCO ESTUARY**

Principal Investigator: Theodore C. Foin
University of California, Davis

Proposal Starting Date: 1 January 2002

Period of Support: 3 years

Budget Requested: $113793.78

THE PROBLEM: MINIMIZING INVASIVE SPECIES IN RESTORING TIDAL MARSHES IN THE SAN FRANCISCO ESTUARY

Successful wetlands restoration is one of the core goals of the CALFED program. Although many specific restoration programs have been proposed and funded, the need for scientifically rigorous experiments with repeatable results and adaptive responses built-in remains a major concern of the agency. One of the most serious problems affecting restoration success is the distinct possibility that a restored marsh might be dominated by an undesirable invasive species, an outcome that might be worse than the degraded marsh it was intended to replace. Some marsh biologists have even expressed concern that marsh restoration should not proceed without an effective program to prevent invasion by aggressive exotics (D. R. Ayres, personal communication).

The threat of invasive plants to the tidal marshes of the lower Delta and San Pablo Bay regions of the San Francisco Estuary is most certain for two species. One is smooth cordgrass (*Spartina alterniflora*), a serious problem in fully tidal salt marshes of San Francisco Bay. Don Strong and colleagues are currently working on the former, mostly in San Francisco Bay but also in Washington. The other species is perennial pepperweed, *Lepidium latifolium*, a tall forb which occurs throughout the Estuary, in alkali sinks, in cool deserts and even annual and perennial grasslands, through which it spreads with ease (Mark Renz, unpublished research).

Lepidium latifolium has received much less attention but it may actually be the more dangerous of the two species. It has vital attributes and a life history that are characteristic of prototypic exotics (Rejmanek, 1996). It is a member of the mustard family (Cruciferae), a family known for having many weedy species, numerous small and easily dispersed seed, and ability to reach large sizes. *Lepidium latifolium* shares these family traits; in addition, it is large (reaching 1 m or more in height) and highly fertile (freely produces lateral branches, each with numerous flowers and small, easily dispersed seed). *L. latifolium* grows fast and has a large, aggressive root system, which enables it to compete effectively with other perennials while retaining the reproductive effort of

annuals, It reproduces by both sexual and vegetative means (Trumbo, 1994). Furthermore, *L. latifolium* may compete with other species by pumping salt ions from deep in the soil profile to the surface, making the immediate surroundings less suitable for other species (Blank and Young, 1997).

One known weakness in the biology of *L. latifolium* is that it is not effective in colonizing the upper marsh. It has some ability to tolerate or survive saturated conditions and the elevated soil salinities found there, but is not known to grow well under these conditions (Chen et al, 2001; May, 1995; Young and Turner, 1995). Consequently, *Lepidium latifolium* poses its gravest threat to the streamside zone, which generally has moderated salinity, abundant water, and better drainage. Despite its relatively recent introduction into Pacific tidal marshes, *L. latifolium* has spread quickly along stream courses, and is considered a serious invader of this zone from full salt marshes upriver to muted tidal and freshwater marshes. In our opinion, its aggressive growth, euryhaline tolerance, persistence in face of attempts to eradicate it and its potential for altering the functional role of estuarine vegetation through competitive displacement make it a very serious threat to marsh restoration programs.

PROPOSAL JUSTIFICATION

Although we naturally focus on invasive species with greater economic or ecological impact, there is little conceptual distinction between biological invaders and recolonization by native species. Colonization by any species is the joint product of site invasibility and those vital attributes of the potential colonist that facilitate its dispersal and colonization. This proposal is organized around this basic principle, focusing upon the relative impact of each component of colonist demography and physiological requirements and environmental resistance.

Prior research with *L. latifolium* suggests 1) that seed dispersal is not limiting; 2) that once plants produce large rhizomes, they cannot be easily displaced; and 3) the critical demographic phase is in establishment and maturation in the first year. Maturation is particularly important since these plants subsequently become local seed sources. Since experience shows that adequate control after establishment is at best difficult and environmentally disruptive, colonization of restoration sites by *Lepidium* must be prevented by some combination of increased site resistance and exploitation of demographic bottlenecks. We seek to estimate the risk of *Lepidium* establishment by measuring site invasibility and defining its colonization strategies from its biological and ecological traits. We can then combine both types of information to test the invasion success by *L. latifolium* in simulated marsh stands and environmental conditions. The goal of this research is to minimize the spread of pepperweed by elucidating the conditions under which it is favored and by potentially providing the opportunity to exploit weaknesses in the life history and population biology of *L. latifolium* to control its spread throughout Estuary marshes.

Adaptive management is expected to be of less concern with this proposal than with restoration programs. Because the research is with a dangerous exotic, most of it will be in the laboratory under controlled conditions. Experiments that do not turn out as

expected are a problem of ordinary science; the adjustments are technically part of adaptive management, but the potential negative consequences are much smaller. The final field tests can fail, and lead to growth and establishment of *Lepidium* despite the design and expectations. The appropriate response under these conditions will be to destroy the *Lepidium* at the end of the first year.

OBJECTIVES OF THIS PROPOSAL

This proposal has three specific objectives.

1. To determine the properties of tidal marshes governing their invasibility by exotic species, with special regard to different positions in the wetland landscape.

2. To determine the combination of reproductive life history strategies and environmental characteristics that are associated with *Lepidium latifolium* invasibility.

3. To test the emerging model of ecological influences on colonization by *Lepidium latifolium* on simulated tidal marshes.

The outcome of this project should be a much-improved picture of the requirements and responses of *Lepidium latifolium* in marsh environments, and possibly a strategy for minimizing its dispersal. As such, this research will provide the biological foundation upon which a control strategy can be built.

PROPOSED APPROACH

Objective 1. To determine the properties of tidal marshes governing their invasibility by exotic species, particularly Lepidium latifolium.

It is important to discover which attributes of tidal marshes in the San Francisco Estuary are key determinants of successful pepperweed colonization. Our previous research has shown that *L. latifolium* is largely restricted to the streamside zone in tidal marshes; often the smaller channels in the marsh are delineated by a mixture of *fringing Scirpus* spp. and *Lepidium*. Our mathematical model (developed from the conceptual model in Foin *et al.* 2000) suggests that a combination of more abundant water supply and regular flushing of salinity acts to open these sites to *Lepidium* colonization. Conversely, the upper marsh may have persistent high water levels with too highly elevated soil salinity to support *Lepidium* invasion. Thus, the principal focus of this phase of the research will be the streamside zone.

In order to elucidate environmental factors contributing to *Lepidium latifolium* invasion, canonical correspondence analysis (hereafter abbreviated to CCA) will be used to regress streamside species and sampling units against environmental factors. CCA

allows the user to compare species and distribution patterns and environmental variables in a single step by combining regression with multivariate analysis. The sampling units will consist of 1 m^2 units. The analysis will be run using *Lepidium* as an environmental factor in order to examine species correlations, and then with pepperweed grouped with the other species to affirm that salinity is the dominant gradient responsible for segregating species and to suggest other factors which may be significant determinants. Data will be collected at multiple sites along a salinity gradient ranging from full strength seawater (western San Pablo Bay sites) to fresh water (Suisun Marsh). The exact sites to be sampled will include Rush Ranch and Petaluma Marsh, plus a series of younger marshes to be chosen from sites along San Pablo Bay and others in the Suisun Marsh in Solano County. A minimum of 20-1 m^2 samples will be collected from each site. Species composition, percent cover, and several environmental variables (channel salinity, soil salinity, flooding regime interpolated from tide tables, pH, soil particle size, and percent organic matter) will be recorded for each sample. Sampling will be conducted in one short time period at each site, but can be repeated in subsequent years if the analysis requires it.

The results will be analyzed using PC-Ord (McCune, 1999) for CCA. We expect the results to confirm the hypothesis that increasing salinity is the dominant environmental factor limiting successful pepperweed invasion. This hypothesis was developed from a 2001 experiment measuring growth under different salinity and flooding conditions under controlled conditions. We next need to confirm these results in the field, with natural conditions of tidal input and soil. It will be particularly important to examine the influence of these covariates as clues to the mechanisms limiting *Lepidium*.

Objective 2. To determine the combination of reproductive life history strategies and environmental characteristics that are associated with Lepidium latifolium invasibility.

Two principal means for pepperweed dispersal (rhizome fragmentation and seed dispersal) have been documented. Field observations have shown that broken rhizomes are an important source of propagules for dispersing pepperweed (M. Renz, pers. comm.). This is a difficult mechanism to study, given the erratic dispersal of broken rhizomes and the numerous conditions that can influence their growth. The difficulty in making satisfactory experimental measurements of rhizome establishment rates is a daunting problem. We concede that rhizomes are probably important propagules, especially after a reproducing population has established either locally or at some location upstream of the site. Our best evidence of significant colonization by rhizomes may be indirect, resulting from seeing successful establishment in the field that cannot be accounted for by seedling germination and growth.

The rapid establishment of *Lepidium* across the western states suggests that seed dispersal is probably the principal means of expansion. *L. latifolium* routinely produces numerous seed, but to date the role of seed in colonization has not been quantified. The copious seed suggests that wind and animal dispersal are important mechanisms for

pepperweed colonization, at least in streamside habitats, and perhaps the most important one.

Seed dispersal and early growth. Because seed are both numerous and readily dispersed, it seems safe to assume that dispersal is not a major limiting factor on *Lepidium* invasibility, and instead concentrate upon establishment.

Experimental seeding in the field has obvious flaws and dangers, so laboratory experiments will be the principal means for assessing the reproductive strategies of *Lepidium latifolium*. This research will examine the success of reproduction from seed in relation to the nature of the stand. We propose to seed pepperweed into stands of native streamside dominants of varying densities, from bare ground to normal densities under different salinities (0, 15, 35 ppt - the range of salinities found in the streamside zone in the Estuary) in the laboratory for better control over site conditions. *L. latifolium* will be seeded into stands of native dominants (*S. acutus, S. americanus. S. maritimus*) to determine the importance of seedling survivorship to *L. latifolium* expansion. This will be a randomized complete block design with salinity assigned to the main plots and *Scirpus* cover randomly assigned within blocks. The number (estimated by weight of seed sown) of *L. latifolium* seeds will be constant across treatments. The response variable will be the estimated number of germinated seeds and number surviving to seedlings and adulthood, broken down into size groups (height <5cm, 5-30 cm, 30-60 cm, and >60 cm). There will be 8 replicates per treatment. Results will be analyzed with ANOVA and quantified by regression equations. We hypothesize that these competitive relationships, in the context of prevailing salinity conditions, will determine the rate of *Lepidium* growth and its long-term establishment.

Post-colonization growth and establishment. *Lepidium latifolium* can be expected to compete against the tules (*Scirpus* spp.) normally found in the streamside zone. The previous experiment should tell us how much tule stands can be expected to resist *Lepidium* invasion. The effect of *Lepidium* on *Scirpus* spp. is the subject of the next experiment. To assess the potential for competitive displacement of tules in tidal marshes, growth responses of *Lepidium latifolium* will be compared to three native wetland streamside dominants (the same three *Scirpus* as in the seeding experiment)across a range of salinity treatments. The experiment monitors the growth of each of the three species in growth boxes under three salinity treatments (0, 15, 35 ppt) and two flooding regimes (daily, every 4th day). The experimental design is a split plot design with salinity as the main plot, flooding regime the subplot, and species identity randomly assigned to the subplots. Plants will be propagated from root stock. There will be four replicates per treatment, and four subsamples in each sampling unit to reduce variability of root stock. The number of replicates is constrained by the number of treatments and plumbing constraints. Preliminary results from a pilot experiment done this year indicate that this is an adequate number of replicates for the variance expected. Above- and below-ground biomass will be collected at the end of the growing season. Growth response will also be monitored throughout the growing season by repeatedly measuring the growth of randomly selected stems in each experimental unit Results will be analyzed with repeated measures ANOVA.

Objective 3. To test the emerging model of ecological influences on colonization by Lepidium latifolium on simulated tidal marshes.

The results from earlier experiments will allow us to identify those species and environmental variables having the greatest effect on *Lepidium* invasion success. These results will permit us to establish stand conditions that should vary with respect to suitability for *Lepidium* seedlings. Such stands will be planted as a validation experiment, set up in mesocosms that will have simulated tidal and salinity conditions to match the combinations having the greatest effect on invasibility. The design will be a randomized complete block design with five replicates. The treatments will be selected from the series of conditions elucidated above that are most applicable to pepperweed invasion. Satisfactory rank order in invasion success will serve to test our understanding.

Successful validation will open the possibility for field tests of planting strategies that can be tested in sites being restored in the field. Although this aspect remains too preliminary to promise as a finite objective, such field experiments will be discussed in our interactions with the Simenstad-Reed-Phil Williams team and the DWR marsh restoration program, both of which will be conducting restoration programs and who have indicated their willingness to collaborate with us. Since we will not deliberately introduce *Lepidium* seed into the field, we will require sites at which pepperweed is already present in the general area. Field validation is one way to address any lingering concerns about our ability to produce satisfactory mescosms (see Callaway *et al.*1997). Whether or not field validation can be performed, we expect this proposal to identify species, planting schemes and environmental conditions which have the greatest exclusionary impact on pepperweed.

FEASIBILITY

This proposal is based on methods that have been well tested in ecology, marsh biology and the field in previous research leading up to this one. The laboratory-based and field survey elements of this proposal are demonstrably feasible and no insurmountable problems are expected to arise therein.

The final field-based tests of *Lepidium* exclusion will require permits. We hope to be included in existing or forthcoming permits at Simenstad-Reed Williams and/or DWR sites. The exact design elements cannot be specified until the laboratory results are in and analyzed, but hopefully will result in feasible restoration schemes (planting densities, species type, and predominant hydrologic-geomorphic conditions).

PERFORMANCE MEASURES

The only aspect of this proposal subject to specification of a successful performance evaluation will be the field experiment. Once the treatments are in place, the experiment will have to be routinely monitored for *Lepidium* colonization, most likely over a two-year period to allow for two germination and growth cycles. *Lepidium*

seedlings appearing in the site are not sufficient to judge the experiment a failure; *Lepidium* must grow and produce seed to meet this condition. If *Lepidium* seed are locally available but there is no successful colonization within the two years, the experiment will be deemed successful.

DATA HANDLING AND STORAGE

All data will be stored in a data vault system maintained and backed up in the Computing Facility of the Department of Agronomy and Range Science, University of California, Davis. Results will be posted to our website at agronomy.ucdavis.edu.

OUTCOMES AND EXPECTED BENEFITS OF THIS RESEARCH

If the research progresses as outlined, we think a testable *Lepidium* prevention strategy will emerge before the end of the project term. By elucidating the conditions under which pepperweed is favored and by potentially providing the opportunity to exploit vulnerabilities in its life history and population biology to control its spread, we should be able to develop an improved picture of the requirements and responses of *Lepidium latifolium* in marsh environments, and possibly a strategy for minimizing its dispersal. This can be further tested in the field or implemented without increasing the risk of *Lepidium* invasion.

We shall participate in future CALFED science conferences, publish in regular journals, and perhaps produce a manual on planting and environmental management that minimizes the risk of *Lepidium* invasion.

WORK SCHEDULE

Objective	Task	Timeframe
1	field survey using CCA	June-September 2002
2	experimental seeding into *Scirpus* spp.	May-October 2002
2	growth in competition with *Scirpus* spp.	May-October 2003
3	mesocosm tests in simulated streamside stands	February-September 2004
3	field verification	February 2005-October 2006

The off-season (November-February) is reserved for data analysis. Above-ground material will be collected from Rush Ranch to support a regression of plant height against biomass for each species. In the fall of 2001, native streamside dominants will be placed into growth chambers to grow them out for the stands of the seeding

experiment beginning in the spring, 2002. We will collect data on species and environmental factors for the CCA in the summer of 2002. In the spring of 2004, the mesocosm experiments will begin and will continue through the fall. Technically, field verification proceeds beyond the term of this proposal, although planting of experimental stands will likely be completed in 2004. Details of monitoring will continue, but exact arrangements will have to be made later.

Applicability to ERP Goals

The four ERP goals applicable to this proposal are:

Goal 1: *protection and restoration of native biotic communities*

Goal 2: *Rehabilitate natural aquatic and adjacent plant communities to support native members of those areas*

Goal 4: *Protect and/or restore functional habitat types in the Bay-Delta estuary and its watershed for ecological and public values such as supporting species and biotic communities, ecological processes, recreation, scientific research, and aesthetics, including restoration of tidal marsh, sloughs, seasonal and riparian wetlands and protecting tracts of existing high quality wetland*

Goal 5: *Prevent establishment of additional non-native invasive species and reduce the negative ecological and economic impacts of established non-natives in the Bay-Delta estuary and its watershed, including where possible limiting spread or eradication of non-natives*

The proposed research will directly address each of these four goals. *Lepidium latifolium* is specifically identified as a major problem in the Bay-Delta estuary and its watershed. This species poses a grave threat to remaining wetlands in the Bay-Delta system and to proposed restoration projects because it is highly successful across a wide spectrum of wetland habitats. This research seeks to provide a mechanistic understanding of the way in which *L. latifolium* is able to invade a wetland site with respect to the invader and the environmental characteristics of the site. Development of a successful control protocol would help protect remaining intact systems; provide a means for reducing its spread; and prevent the invasion of *Lepidium latifolium* into restoring sites.

PREVIOUS CALFED SUPPORT

I have support from the Science Advisors funds (30K) to support mathematical modeling population dynamics of splittail. *Pogonicthys macrolepidopterus*. This work is completely separate from this proposal.

SYSTEM-WIDE ECOSYSTEM BENEFITS

This proposal seeks to develop and test the adequacy of a protocol to address the invasibility of tidal marshes, and secondarily to find management schemes which

maximize exclusion of pepperweed. To the extent to which this proposal is productive, we can expect to improve restoration by excluding *Lepidium*, and perhaps develop a protocol that can be used for a larger number of invasive plant species.

QUALIFICATIONS

ABBREVIATED CURRICULUM VITAE
THEODORE C. FOIN
Updated 9 October 2000

EDUCATIONAL SUMMARY

A.B., Biological Sciences, Stanford University, 1962
Ph.D., Zoology (Ecology), University of North Carolina, Chapel Hill, 1967

CURRENT ACADEMIC POSITION

Professor
Department of Agronomy and Range Science
University of California, Davis 95616
1998-Present

ROUTINE TEACHING RESPONSIBILITIES

ASE 121. Systems Analysis in Agriculture and Resource Management
Ecology 200B. Principles and Application of Ecological Theory.
Ecology 201. Modeling Ecosystems and Landscapes

GRADUATE EDUCATION

Member of the Graduate Groups in Ecology, International Agricultural Development, Horticulture and Plant Biology.
18 MS and 11 PhD students have finished under my direction over the course of my career; 3 PhD and 2 MS are in progress.

RECENT PROFESSIONAL AND PUBLIC SERVICE

Editorial Board, *Population and Environment*
Yolo County Grand Jury, 1991-92
Member of the following professional societies: American Institute of Biological Sciences, California Botanical Society, Ecological Society of America, International Society of Ecological Modelers, Sigma Xi
Chair of Committee of Science Advisors and member of the Board of Directors, San Francisco Estuary Institute.
Member of Science Review Committee, Regional Wetlands Goals Project, San Francisco Estuary Institute.

RESEARCH INTERESTS

My principal activities fall in the following areas:

* The theory and practice of ecological modeling.
* Management-oriented simulation of rice-weed interactions, with special respect to competition for light. Projects in this area are in progress in California and tropical Asia.
* Ecology and simulation of tidal salt marshes and their inhabitants. Current work is focussed on California clapper rails in the San Francisco Estuary, and their relative dependence upon stream evolution and the vegetation.
* Tidal marsh landscape dynamics of the San Francisco Estuary.

RECENT PUBLICATIONS

Foin, T. C., E. J. Garcia, R. E. Gill, S. D. Culberson, and J. N. Collins. 1997. Recovery strategies for the California clapper rail (*Rallus longirostris obsoletus*) in the heavily-urbanized San Francisco estuarine ecosystem. Landcape and Urban Planning 38:229-243.

Foin, T. C., S. P. D. Riley, A. L. Pawley, D. R. Ayres, T. M. Carlsen, P. J. Hodum, and P. V. Switzer. 1998. Improving recovery planning for the conservation of threatened and endangered taxa. Bioscience 48: 177-184.

Caton, B. P., T. C. Foin, K. D. Gibson, and J. E. Hill. 1998.A temperature-based model of direct-water seeded rice (*Oryza sativa*) stand establishment in California. Agricultural and Forest Meterology 90: 91-102..

Gibson, K. D., T. C. Foin, and J. E. Hill. 1999. The relative importance of root and shoot competition between water-seeded rice and watergrass. Weed Research 39: 181-190.

Caton, B. P., T. C. Foin, and J. E. Hill. 1999. A plant growth model for integrated weed management in direct-seeded rice. I. Development, parameterization, and monoculture growth. Field Crops Research 62: 129-143.

Caton, B. P., T. C. Foin, and J. E. Hill. 1999. A plant growth model for integrated weed management in direct-seeded rice. II. Validation testing of water-depth effects and monoculture growth. Field Crops Research 62: 145-155.

Strange, E. L. and T. C. Foin. 1999. Interaction of physical and biological processes in the assembly of stream fish communities. Pp. 311-337 in: Ecological Assembly Rules: perspectives, advances, retreats. (E. Weiher and P. A. Keddy, eds.) 1999. Cambridge University Press.

Caton, B. P., T. C. Foin, and J. E. Hill. 1999. A plant growth model for integrated weed management in direct-seeded rice. III. Interspecific competition for light. Field Crops Research 63: 47-61.

Sanderson, E. W., S. L. Ustin, and T. C. Foin. 2000. The influence of tidal channels on salt marsh vegetation. *Plant Ecology* 146: 29-41.

Foin, T. C. 2000. One for models, and models for all. Review of *An Illustrated Guide to Theoretical Ecology*. Conserv. Biol. 14: 1214-1215.

Gibson, K.D., J.E. Hill, T.C. Foin, B.P. Caton, and A.J. Fischer, 2001. Cultivar interference with the growth of watergrass (*Echinochloa* species) in water-seeded rice. *Agronomy Journal* 93: 326-332.

Gibson, K. D., A. J. Fischer and T. C. Foin. 2001. Shading and the growth and photosynthetic responses of *Ammannia coccinea*. *Weed Research* 41: 59-67.

Caton, B. P., A. M. Mortimer, T. C. Foin, J. E. Hill, K. D. Gibson, and A. J. Fischer, 2001. Weed morphology effects on competitiveness for light in direct-seeded rice. *Weed Research* 41: 155-163.

Gibson, K. D., J. L. Breen, J. E. Hill, B. P. Caton, and T. C. Foin. 2001. California arrowhead (*Sagittaria montevidensis*) is a weak competitor in water-seeded rice (*Oryza sativa*). *Weed Science* 49: 381-384.

Sanderson, E. W., T. C. Foin, and S. L. Ustin. 2001. A simple empirical model of salt marsh plant spatial distributions with respect to tidal channel networks. *Ecological Modelling* 139: 293-307.

IN PRESS

Culberson, S. D., T. C. Foin, and E. W. Sanderson. 2000. Vegetation and tidal marsh hydrology of three marshes within the San Francisco Bay/Delta estuary, CA, USA. *Proceedings of the 16th Annual Conference, Society of Wetlands Scientists, Quebec City.*

Caton, B. P., K. D. Gibson, T. C. Foin, and J. E. Hill, 2001. Evaluating the potential contribution of simulation models to the identification of competitive crop traits. *Field Crops Research.*

Moyle, P. B., R. D. Baxter, T. Sommer, T. C. Foin, and R. R. Abbott. Sacramento splittail white paper.

SUBMITTED

Foin, T. C., C. M. Efferson, L. M. Veilleux, R. O. Spenst, M. F. Coe, and J. D. Ficker. Predicting invasion potential of a major predator: northern pike (*Esox lucius*) in California. *Biological Invasions.*

Caton, B. P., A. M. Mortimer, J. E. Hill, and T. C. Foin. 2001. Water depth effects on the growth and root-shoot dynamics of two rice varieties and two *Echinochloa* spp. *Field Crops Research.*

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Blank, R. and Young, J. A. 1997. *Lepidium latifolium*: Influences on soil properties, rates of spread, and competitive stature. Pages 69-80 in J.H. Brock, M. Wade, P. Pysek and D Green, eds., Plant Invasions: Studies from North America and Europe. Backhuys Publishers, Leiden, the Netherlands.

Callaway, J. C., J. B. Zedler, and D. L. Ross. 1997. Using tidal salt marsh mescosms to aid wetland restoration. Restoration Ecol. 5: 135-146.

Chen, H., R.G. Qualls, G.C. Miller. 2001. Adaptive responses of *Lepidium latifolium* toto soil flooding: biomass allocation, adventitious rooting, aerenchyma formation and ethylene production. Plant Physiology. Submitted.

Culberson, S.D. 2001. The interaction of physical and biological determinants producing vegetation zonation in tidal marshes of the San Francisco Bay/Delta, California, USA. Unpublished Ph.D. Dissertation, University of California, Davis. 148 pp.

Foin T. C., S. D. Culberson, and M. R. Pakenham-Walsh. 2000. A productivity-based model of tidal hydrology influence on marsh vegetation. Abstracts of the CALFED Science Conference, p. 175.

May, M. 1995. *Lepidium latifolium* L. in the San Francisco Estuary. 16 pp.
McCune, B. 1999. PC Ord Version 4. Multivariate analysis of ecological data. MJM Software Design.
Rejmanek, M. 1996. A theory of seed plant invasiveness: the first sketch. Biological Conservation 78: 171-181.
Trumbo, J., 1994. Perennial pepperweed: a threat to wildland areas. Cal EPPC News 2: 4-5.
Young, J.A. and C. Turner, 1995. *Lepidium latifolium* L. in California. Cal EPPC News 3: 4-5.

Budget Justification

INVASION DYNAMICS OF PERENNIAL PEPPERWEED, *LEPIDIUM LATIFOLIUM*, AND THEIR CONSEQUENCES FOR PROTECTION OF WETLANDS IN THE SAN FRANCISCO ESTUARY

Direct Labor Hours and Salary

This proposal has been expanded to two research assistants because of the increased research commitments. Rene O. Spenst will have control over the herbicide and seed establishment experiments with standard salary (9 months@50%, 3 months at 100%: total stipend $19200). A second RA has been added to assist with the field correlation analysis and to have primary control over seed dispersal and demography. Provision for two undergraduate assistants has also been made at $7.50/hr.

Benefits

Benefit Rate is 3% for all students.

Travel

3 months per year for a University truck has been included, with extra for travel to meetings and mileage.

Supplies and Expendables

All supplies are directly for the project, mostly in buckets, lumber, and seed trap supplies.

Services or Consultants

Funds are included for endangered species surveys mandated by the permit coonditions.

Other Direct Costs

Fee remissions for Ras are included @ $5147/person/year.

Indirect Costs

A uniform rate of 10% (negotiated state-UC rate) is assumed.

Budget Summary

INVASION DYNAMICS OF PERENNIAL PEPPERWEED, *LEPIDIUM LATIFOLIUM*, AND THEIR CONSEQUENCES FOR PROTECTION OF WETLANDS IN THE SAN FRANCISCO ESTUARY

Year 1	**2003**										
Task No.	Task Description	Man Hours	Salary	Benefits	Travel	S&E	Services	Eqmt	Other DC	IDC	row subtotals
1	CCA		15360	460.8	2377	300	8000	2200	10294	3285.739	47685.039
1	CCA	700	5250	157.5							17273.1
3	seed establishment		3840	115.2							11865.6
4	herbicide		7680	230.4							7910.4
col.subtotals		700	32130	963.9	2377	300	8000	2200	10294	32857.39	**84734.139**

Year 2	**2004**										
Task No.	Task Description	Hours	Salary	Benefits	Travel	S&E	Services	Eqmt	Other DC	IDC	Total
2	seed dispersal		24960	748.8	3200	1500	4000		10294	7085.42	53024.22
2	seed dispersal	160	1200	36							8541
3	seed establishment		5760								7305
3	seed establishment	200	1500	45							1545
4	herbicide expt	160	1730.4								1730.4
4	herbicide expt		7680								7680
col subtotals		520	42830.4	829.8	3200	1500	4000	0	10294	70854.2	**79825.62**

2005											
Task No.	Tsk Description	Hours	Salary	Benefits	Travel	S&E	Services	Eqmt	Other DC	IDC	Total
4	herbicide expt		19200	576	3000	1500			5314.1	4353.63	47889.93
4	herbicide expt	320	2400	72							2472
2	seed dispersal	200	1540	46.2							1586.2
2	seed dispersal		9600	288							9888
column subtotals			32740	982.2	3000	1500	0	0	5314.1	43536.3	**61836.13**

Proposal Totals

2003	84734.14